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EUGENE v. GOTHARD

By BARON BÉLA HARKÁNYI

Eugene v. Gothard was born in Herény (Hungary) as the eldest son of the landed proprietor Stephen v. Gothard on May 31, 1857. He inherited his love for natural sciences, and especially for physics, from his grandfather, Francis v. Gothard, who occupied himself a great deal from 1780 to 1830 with botany and physical experiments. The nice old electric machine still to be found in the Herény observatory was often used by him in those days. The father of Eugene spoke very often to his eldest son about these old experiments and encouraged the boy in his predilection for physics, when he studied at the gymnasium at Szombathely, and gave him opportunity to make experiments with steam engines and electric motors in a small laboratory for his own use. After leaving the gymnasium, in 1875, Eugene went to Vienna and for four years pursued his studies at the Polytechnic in the department of mechanical engineering. He attended the lectures of Professor Herr on geodesy and of Professor Tinter on astronomy with great assiduity, and worked a great deal in the course in practical mechanics. After completing his course in Vienna he traveled in foreign countries. Upon returning home, he intended to build a physical laboratory on his own estate in Herény, but later on—partly under the influence of his friend Nicolaus v. Konkoly—he changed his plan and founded the Astrophysical Observatory in Herény.

The buildings of the observatory were finished in 1881, the equip-

ment completed in 1882; observations had already commenced in the autumn of 1881, in the dome then ready for use. This contained the principal instrument of the observatory, a 10¼-inch (260 mm) Newtonian reflector of 77 inches (1967 mm) focal length, with a silver-on-glass mirror. This instrument was originally constructed by Browning for N. v. Konkoly of Ó-Gyalla, and had proved excellent during seven years of spectroscopic and micrometric work there. Von Gothard made several important changes in it, and attached to it a new 4½-inch guiding telescope, thus transforming it into an instrument well adapted for astrophotographic use. The smaller instruments were a portable transit instrument, two clocks, and several spectroscopes, with all the auxiliary apparatus needed, and a set of meteorological instruments. Besides these, we must mention a rich collection of more than 200 physical instruments for different uses, built mostly in the workshops of the observatory in the early stage of its development; most of them served only for learning the methods of making and using them and for training in physical laboratory work. A few of them were often used in later researches. The whole outfit was completed by an electric-light plant, a gas apparatus for laboratory use, and a complete workshop. Besides E. v. Gothard, the staff of the observatory consisted until 1883 of his brother Alexander, who was also owner of the establishment, and of their youngest brother Stephen who, while a student at the gymnasium, assisted occasionally in the observations, and of J. Molnár as mechanician.

The first larger publication of the institution, entitled *Publikationen des astrophysikalischen Observatorium zu Herény in Ungarn*, I. Heft, appeared in 1884 and contains the detailed description of the observatory, observations of spectra of the brighter stars made in 1881–1882 with a spectroscope attached to the eyepiece of the instrument, without slit and cylindric lens, and observations of the surface of *Mars* and *Jupiter* (1881–1882) made by Alexander v. Gothard, and a few other miscellaneous observations of the same epoch.

Later on, von Gothard devoted himself mainly to the study of the spectra of heavenly bodies, and published his first paper on the spectrum of Comet 1882 II in the *Astronomische Nachrichten* (**103**, 377, 1882); then followed the researches on the spectra of Comet

Brooks-Swift (1883), of Comet 1884 I, of γ *Cassiopeiae* and β *Lyrae*. In the paper on the new star in the *Andromeda* nebula (*Astronomische Nachrichten*, **112**, 390, 1885) he mentions his first experiments on the use of photography for observations of nebulae, a method he had previously employed for the solar eclipse in 1882. The interesting photograph of a meteor accidentally crossing the field of his reflector during an exposure on some other object, and forming a trail like a comet, was made in his earliest photographic researches. His first success in comet photography came in the autumn of 1886, when he obtained a photograph of Comet 1886 IX. After the observations on the spectrum of *U Orionis*, he published his first account of his most interesting photographs of nebulae, to which were devoted many years of his assiduous work, and increased a great deal our knowledge of the constitution of the nebulae. The discovery of the small star in the *Lyra* nebula was considered somewhat doubtful at first by several observers, but was universally recognized as certain after having been thoroughly verified by others. His first photographs showed the great advantage of the new method over visual observations, and on his photographs of comparatively small size von Gothard obtained delicate details which were lacking on the best drawings made with large instruments, or appeared there only as slight traces. Professor Vogel in Potsdam examined very closely some of von Gothard's photographs, and requested Mr. S. Widt to make elaborate drawings of five nebulae, believing that only well-made drawings are able to show all the fine details of the originals (*Astronomische Nachrichten*, **119**, 337, 1888). He emphasizes the fact that small condensations of the nebulous matter can always be easily distinguished from star-images by examining carefully the silver deposit on the plate. He could make very exact measures of well-marked details on the photographs. The excellence of von Gothard's photographs can also be seen on his photographs of the small nebula near *B.D.* $+34^{\circ}.980$ and of the small nebula, *M 57*, discovered by Barnard; in this case he succeeded in verifying the existence of these very faint objects with his comparatively small instrument, though only the Lick telescopes seemed to be large enough to show them visually (*Astronomische Nachrichten*, **135**, 11, 1894; *Astronomy and Astrophysics*, **13**, 190, 1894).

The photographs of the spectrum of Comet 1892 I show great progress in this line of research (*Astronomische Nachrichten*, **129**, 405, 1892). After some unsuccessful attempts, the plate taken on April 9, 1892, with four hours' exposure, showed a fine, sharp spectrum of the comet from λ 3873 to λ 5673, with much detail, and permitted the identification of the bands in the comet's spectrum with the hydrocarbon bands of the Swan spectrum, as carefully investigated by Professor Eder (1890).

Then came von Gothard's most important investigations of the spectra of gaseous nebulae and the new star in *Auriga*, which led to the interesting discovery of the identity of the nebular spectrum and the spectrum of the *Nova*. The first spectra of the *Nova* were taken with his quartz spectrograph (1892); afterward, on September 12, he tried a 10-inch objective-prism with great success (*Astronomische Nachrichten*, **129**, 93, 1892). He found a spectrum with bright lines showing a great resemblance to the spectrum of the Wolf-Rayet stars and to that of the gaseous nebulae. From the photographs of the nebulae *G. C.* 4964, 4447, 4373, 4514, 4628, and *N. G. C.* 7027, 6891, and 6884, taken with the objective-prism; the plates of the great *Orion* nebula, *G. C.* 1179, and the nebulae *G. C.* 4964 and 4628, taken with the quartz spectrograph, he could determine the wave-lengths of many nebular lines very exactly, and prove in a satisfactory way that seven *Nova* lines were absolutely identical with the corresponding nebular lines, and even the intensities of the lines showed a similar behavior in both cases. Only two lines, near λ 3720 and λ 4642, were not found in some of the nebular spectra. The detailed account of these investigations appeared in Hungarian in the *Memoirs* of the Hungarian Academy of Sciences, III Section, October 17, 1892, and was translated for other scientific journals (*Astronomy and Astrophysics*, **12**, 51, 1893; *Monthly Notices*, **53**, 55, 1893; *Memorie della Società degli Spettroscopisti Italiani*, **21**, 169, 1892).

Von Gothard also carried on similar researches on the spectrum of *Nova Persei* of 1901 with the objective-prism. Many photographs in the spring of 1901 show periodic changes: on certain days the spectrum seemed to be continuous; on other days bright lines appeared, which are characteristic of gaseous nebulae. The length

of the period was about nine days, and the star remained longest in the stage showing the nebular spectrum (*Astronomische Nachrichten,* **155**, 269, 1901, and **157**, 141, 1901). The observations in August 1901 show no further changes in the spectrum, which was then very similar to the gaseous spectrum observed in April, and remained unchanged during all of the following observations. The difference between the gaseous spectrum in April and this spectrum of the later stage was the enhancement of the nebular lines of the first spectrum, the hydrogen lines remaining unchanged. Von Gothard's last paper on astronomical subjects appeared September 6, 1901, in the *Astronomische Nachrichten* (**156**, 283, 1901), concerning the photographic aureola observed around *Nova Persei.* He attributes this phenomenon to the great intensity of the nebular lines λ 3867 and λ 3970, thinking that the photographic objectives used to photograph the *Nova* were not sufficiently corrected for these rays and therefore gave chromatic dispersion-circles around the image of the star.

Besides these astrophysical researches, von Gothard did much spectroscopic work in the laboratory. He used, at first, a spectrograph with a direct-vision Wernicke prism; later on, a fine Rowland concave grating, mounted in Rowland's manner. He published very little about these researches; the most important paper on them is his "Spectrographic Studies," which appeared in Hungarian in 1891 in the *Memoirs* of the Hungarian Academy of Sciences (III Section). It contains a detailed description of the instruments, and extensive measures made on the nitrogen spectrum from λ 3650 to λ 4060. He used the lines of the iron arc as standards, and deduced the wave-lengths of the nitrogen spectrum by a graphical method from the spectrograms taken with the Wernicke prism spectrograph. The final results agree very well with Hasselberg's measures. Other investigations carried on in his laboratory were his experiments on the photography of the electric spark. He began these researches in 1887, and obtained beautiful figures by conducting the discharge of a Wimshurst machine, in a dark room, directly upon the sensitive layer of the plate. The figures were the finest when Leyden jars were used and the back of the plate covered with tinfoil. The figures around the positive pole resembled the roots of a tree; those around

the negative pole were like feathers with very fine detail (Eder's *Jahrbuch für Photographie*, 1889).

Von Gothard occupied himself very much with scientific photography and was thoroughly acquainted with all its methods. He was a real master of this art. He used to try every new material and process in his laboratory, to determine whether they might not prove useful in their application to astronomy or spectroscopy. A large number of papers dealing with these questions appeared from 1888 onward in Eder's *Jahrbuch für Photographie und Reproduktions-Technik*, in the *Photographische Correspondenz*, and *Photographische Rundschau*. The usefulness of photography for astronomy had not been universally acknowledged up to the time of von Gothard's early researches and therefore he was very anxious to prove to the skeptics the great importance of this new method.

Besides his observational work, he found great pleasure in making new instruments and spent much of his time in the workshop, constructing many fine instruments by the most exact and modern methods. He not only made all the apparatus for his own use, but furnished, also, many instruments—transit instruments, spectrographs, and photographic cameras—to outside scientific establishments. Among his new constructions we mention only his wedge photometer with type-printing apparatus, which has served as a model for the photometer of Toepfer used in Potsdam (cf. Müller, *Photometrie der Gestirne*, p. 185), and the fine spectrographs continually used since by Professors Eder and Valenta in Vienna. Some of his new models von Gothard described in the *Zeitschrift für Instrumentenkunde* from 1883 onward; the first of his constructions are treated also in N. von Konkoly's *Praktische Anleitung zur Himmelsphotographie* (1887).

In 1895 von Gothard was made director of the new electric works founded in Szombathely. For many years he remained in this post, devoting his whole energy to the development of the new enterprise, and succeeded in bringing it technically and financially to great perfection. Under these circumstances he could devote himself to scientific work only in leisure hours, and found no more time for researches of any considerable length.

The first signs of a serious heart disease appeared about 1899;

failing health forced him to give up all laborious occupations, and from this time he worked only on rare occasions in his observatory and workshops. He traveled in autumn and winter in the South, mostly in Italy, studying there with great enthusiasm the treasures of ancient art; he visited also Algeria and Egypt. The greater part of the year he spent quietly in retirement in Herény, collecting books and doing some scientific work from time to time. He died May 29, 1909, quite unexpectedly, and was mourned by his relatives and many friends and colleagues. E. v. Gothard was a very kind, reserved man, with great energy, and helpful to everybody who asked aid or advice. He was the recipient of many honors: in 1886 the Voigtländer silver medal from the Vienna photographic society; in 1887 the gold medal of the Vienna photographic exhibition; the highest distinctions of the photographic exhibition of 1889 in Berlin and of 1889 in Moscow. In 1890, he was elected corresponding member of the Hungarian Academy of Sciences in Budapest. He was also a member of the Royal Astronomical Society, of the Astronomische Gesellschaft, and of several other learned societies.

BUDAPEST
October 1909

ON A GREAT NEBULOUS REGION AND ON THE QUESTION OF ABSORBING MATTER IN SPACE AND THE TRANSPARENCY OF THE NEBULAE

By E. E. BARNARD

While photographing the region of the great nebula of *ρ Ophiuchi* (which I had found with the Willard lens) at the Lick Observatory in 1893, the plates with the small lantern lens ($1\frac{1}{2}$ inches diameter, also attached to the Willard mounting) showed a remarkable nebula involving the 4.5 magnitude star *ν Scorpii* (Plate I). It had not been noticed on the Willard lens photograph, where it was very faint and near the edge of the plate. The discovery of this object therefore is due to the small lantern lens.

Roughly this nebula is bounded by the figure formed by the following places (for 1855.0):

α	δ
$15^h\ 59^m$	$-18°\ 20'$
16 4	−18 0
and	
16 10	−21 00
16 16	−18 50

In its fainter portions it involves to the southeast the stars *B. D.* −19°4357, −19°4359, and −19°4361. The last two are in a dense nebulous mass in which on the north following side close to the stars are a thin dark lane and a narrow strip of brighter nebulosity. These two stars are joined to −19°4357, which is itself nebulous, by a thin thread of nebulosity which is well shown in Plate II A. North and following these objects are dark regions where there are apparently very few stars. The extensions of this great nebula reach to, and in a feeble manner connect with, the great nebula of *ρ Ophiuchi*.

The greatest interest in this nebula, however, lies in the fact that it seems to show a veiling of the stars in certain of its portions. Especially is this noticeable at its northern and western end, near the stars −17°4511, −17°4502, and −18°4240. It is quite evident that the thinning out or dimming of the stars in this region, that are apparently in the nebula, is not due to a chance vacancy. The line of demarka-

PLATE I

N

E

W

GREAT NEBULA OF NU *SCORPII*

10-Inch Lens. 1905, April 4, $19^h\,25^m$ to $24^h\,20^m$ G. M. T. Scale: $1° = 37$ mm

The plate covers $3°.9 \times 3°.1$

tion between the rich and poor portions of the sky here is too definitely and suddenly drawn by the edges of the nebula to assume the appearance due to an actual thinning out of the stars. It looks, where this part of the nebula spreads out, as if the fainter stars were lost, and the brightness of the others reduced at least a magnitude or more. This remarkable feature of the nebula is very important to a proper understanding of the region of the great nebula of ρ *Ophiuchi*, which is five degrees south of ν *Scorpii*. In the region of ρ *Ophiuchi* there is every appearance of a blotting-out of the stars by the fainter portions of the nebula, but from its complicated and irregular form the hiding of the stars is not so clearly evident as in the case of the ν *Scorpii* nebula. At present we have no means of determining whether a nebula is transparent or not. The assumption has always been that they are transparent like the comets. The proof of the transparency of comets is easy, but for obvious reasons there can be no similar proof with respect to the nebulae. I think in the present case, however, that the nebula of ν *Scorpii* is shown to be at least partially transparent, but the absorption of the light of the stars behind it must be considerable. The picture is quite conclusive evidence that the nebula is nearer to us than the general background of stars at this point. This fact, unfortunately, is not so evident in the reproduction as it is in the original, an inspection of which would at once lead to the above conclusion.

In connection with the present subject I would call attention to a paper of mine in *Astrophysical Journal*, **23**, 144, March 1906, which describes a very intricate and straggling nebula in this region, connecting the stars π and δ *Scorpii*. I believe this object will ultimately be found, with more sensitive plates and longer exposures, to be connected with the ν *Scorpii* and ρ *Ophiuchi* nebulosities. The accompanying chart, which covers parts of the constellations *Ophiuchus*, *Scorpio*, *Libra*, and *Lupus*, is intended to show the relation of these various nebulosities to each other. There is strong evidence that they are but the brighter parts of one enormous nebula that covers all this region. I have indicated only the brighter portions of these nebulosities, especially in the case of ρ *Ophiuchi*, for that nebula extends in a strongly marked manner for some distance to the east and can be traced for at least 5° in α and $6\frac{1}{2}^\circ$ in δ. Indeed I am

convinced that all this region as far east as *θ Ophiuchi* and beyond is affected with this diffused nebulosity.

The *ρ Ophiuchi* nebula is far more remarkable than that of *ν Scorpii*. Indeed I do not think there is a finer nebula in the entire sky. Even in comparison with the great nebula of *Orion* in some

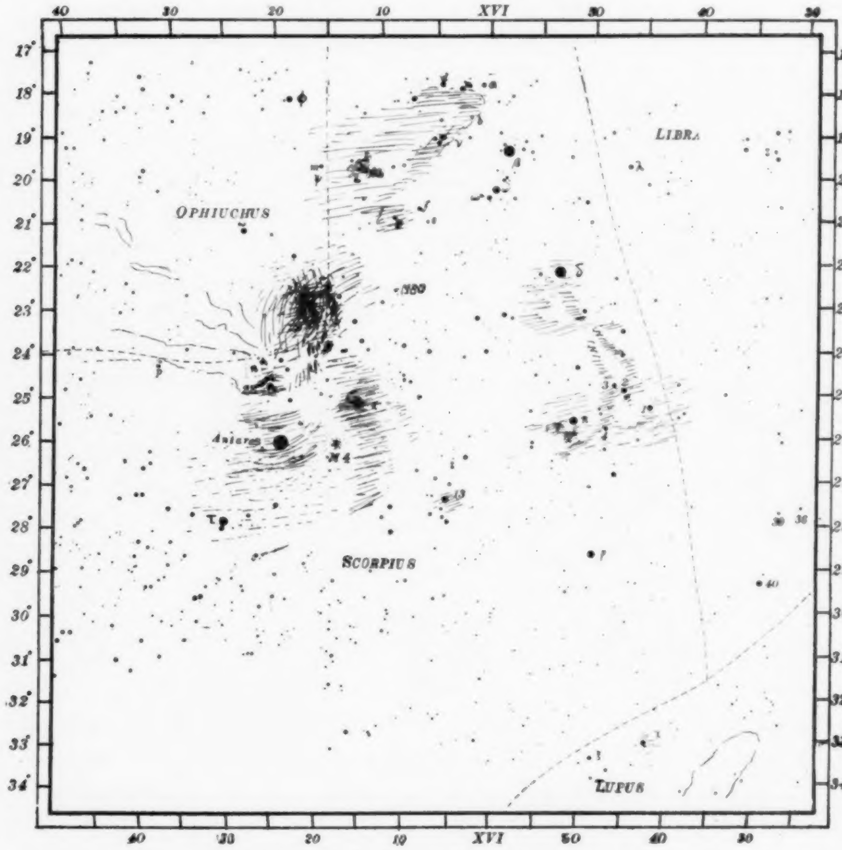
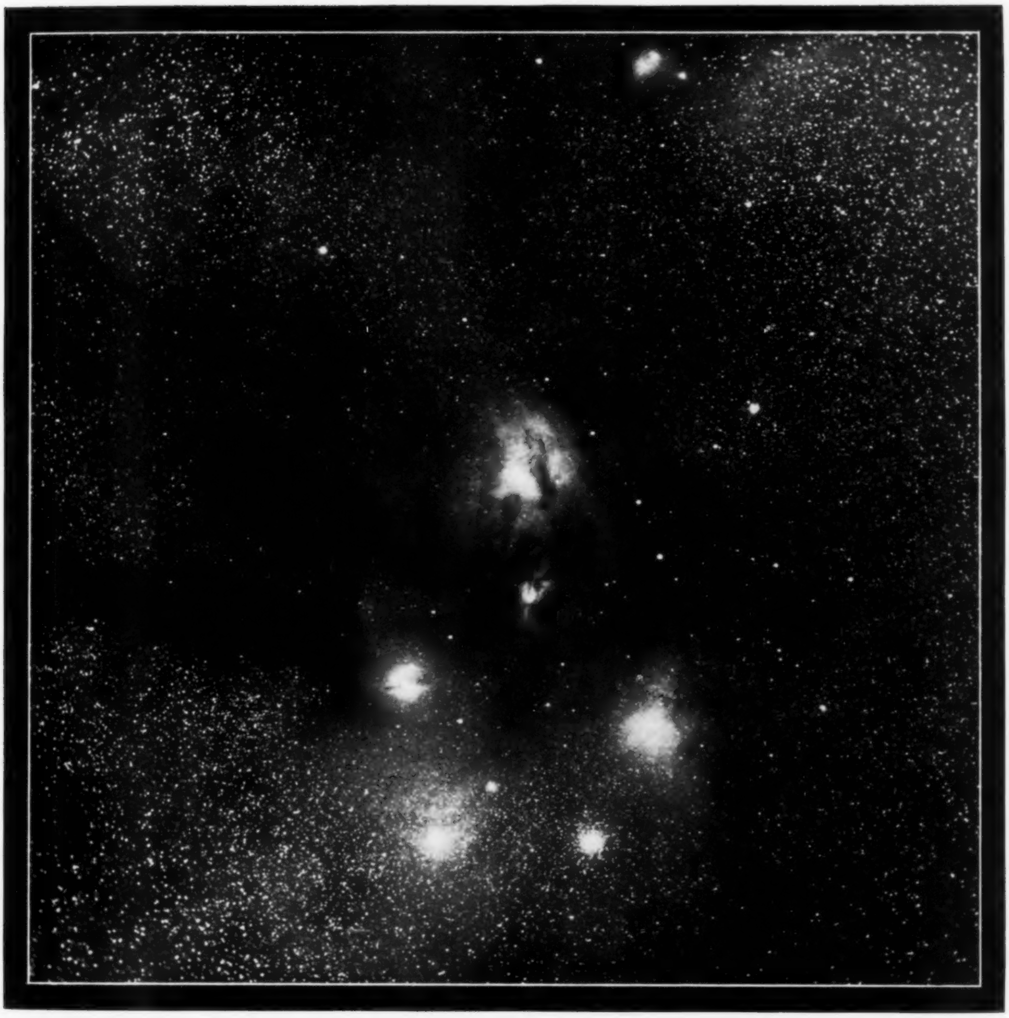


Chart of the Great Nebulous Region

respects it has a deeper interest because of the aspect of the sky near it. It is impossible adequately to describe in detail its extraordinary nature and that of the surrounding region. The reproduction falls far short of doing justice to this subject, though it shows the brighter parts of the nebula fairly well. The dark lanes which run eastward

PLATE II A

N



W

GREAT NEBULOUS REGION OF RHO *OPHIUCHI*

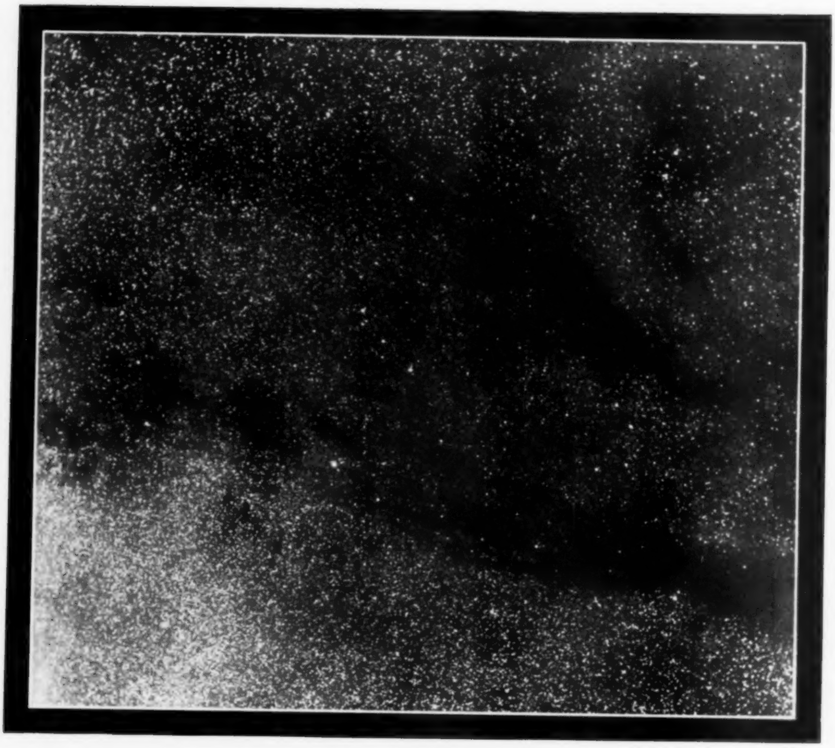
10-Inch Lens. 1905, April 5, $19^h\ 45^m$ to $24^h\ 15^m$ G. M. T. Scale: $1° = 16.7$ mm

The plate covers $7°.7 \times 7°.7$

PLATE II B

N

E



EXTENSION OF VACANT LANES TOWARD THE EAST

Plates overlap slightly. Center of plate at $\alpha = 16^h\ 45^m$, $\delta = 22^\circ$ South

10-Inch Lens. 1905, June 3, $17^h\ 0^m$ to $21^h\ 0^m$ G. M. T. Scale: $1^\circ = 13.5$ mm

The plate covers $7\overset{\circ}{.}6 \times 6\overset{\circ}{.}7$

from it contain very striking black markings, especially the northern one of the two. To me these singular dark features are of as much importance as the bright portions of the nebula, but it has been impossible to bring them out, in the half-tone. The picture shows, however, the striking absence of stars in the space occupied by the main portions of the nebula. To all appearance, the great nebula is located in a hole in a very dense part of the Milky Way, from which vacant lanes extend far to the east. Besides the two main condensations, σ *Scorpii* is involved in a very strong and irregular condensation which is marked by a considerable amount of detail and which spreads in a faint diffusion for several degrees to the south. In addition to the main great condensations there is another one, equally remarkable, 1° due south of ρ at the star *C. D.* $-24^\circ.12684$. This presents a very singular and striking appearance. From the star as a center issue four bright whorls of nebulosity, which are each about 20′ or 30′ long, the two running north and south being the longest. About 14′ north and slightly east is a singular U-shaped dark marking that is so distinct as to appear almost like a defect. Immediately following this condensation is a dark whirlpool appearance which is formed by the beginning of the vacant lanes running to the east.

The two main and largest condensations lie, one, about the triple star ρ *Ophiuchi*, and the other, equally important, precedes it to the west about 30′. This last does not seem to center at any particular star. These condensations are separated by an irregular dark rift 20′ to 30′ long, which runs north and south. North of ρ the nebula assumes a beautiful ribbed appearance which is but feebly represented in the half-tone. The star *22 Ophiuchi* lies between two diverging strips of nebulosity, the northern and upper strip curving around the star. This star and the nebulous strips singularly resemble a human eye, from which fact I have called it "the eye." Waves of nebulosity extend to and beyond *Antares*, diffusing as far south as τ *Scorpii*. At its upper edge this plate (Plate II A) shows the three nebulous stars which are near the lower left-hand corner of Plate I. It also shows a portion of the nebula of ν *Scorpii* about $\frac{3}{4}$ inch or 19 mm (1° 8′) to the west of these stars. Part of the illumination in the extreme upper right-hand corner of Plate II A is due to the

reproduction. The portion of the great *ν Scorpii* nebula which is shown at this point is readily made out (because of its great intensity) 0.9 inch from the right-hand outer edge of the block and 1.1 inches from the upper edge. The rest in this corner is unreal. The diffused nebulosity south of *Antares* is relatively too bright in the half-tone, though it is real.

The star *n* (which is *C. D.* $-24^\circ 12698$) is 0.41 inch north and 0.25 inch east of *22 Scorpii*. It has a narrow strip of nebulosity extending west and south from it for about 6′. This is noticeable on Plate II A.

Among the most remarkable features of this marvelous region are the vacant lanes or streams, previously referred to, extending to the east. The lower or southern of these, which is $\frac{1}{2}^\circ$ broad, is the strongest marked. Its full extent is beautifully shown in Plate II B, which overlaps Plate II A. Its edges are very clearly defined for about 7°, after which it becomes broken and shattered and ends 10° to the east in an irregular group of small holes. The northern and shorter of the two most conspicuous lanes is marked for about 2° with very black, irregular, and sharply defined rifts and perforations which unfortunately are lost in the reproduction. For a history of the discovery of this great nebulous region see *Popular Astronomy*, **5**, 227, September 1897.

I have at other times called attention to the fact that the real connection of this great nebula with such bright stars as *σ Scorpii*, *ρ Ophiuchi*, and others, and its connection with the substratum of small stars of the Milky Way, in which the lanes occur, was a proof of the actual smallness of the stars forming the groundwork of the Milky Way at this point and elsewhere. This must necessarily be true, for the connection with the bright and small stars would imply that the small stars are roughly as near to us as the large ones in this part of the sky, and hence relatively small bodies. If, however, the connection with the small stars is only apparent and the lanes and holes are due to absorbing media between us and the Milky Way, the supposition of smallness would not hold true.

While speaking of these strange dark forms, such as are connected with the *ρ Ophiuchi* nebula, and which are so wonderfully shown on the photographs of the region of *θ Ophiuchi* (*Astrophysical Journal*,

9, 157, 1899, and *Popular Astronomy*, **14**, 579, Dec. 1906), I would call special attention to an object of this class which has been shown on a number of my photographs for the past fifteen years or more. It is a small black hole in the sky, very much like a black planetary nebula. It is round and sharply defined. Its measured diameter on the negative is 2!6. The position is closely:

$$1875.0\ \alpha = 18^h 25^m 31^s,\ \delta = -26^\circ\ 9'.$$

On account of its sharpness and smallness and its isolation, this is perhaps the most remarkable of all the black holes with which I am acquainted. It lies in an ordinary part of the Milky Way and is not due to the presence or absence of stars, but seems really to be a marking on the sky itself.

If these dark spaces of the sky are due to absorbing matter between us and the stars—and I must confess that their looks tempt one to this belief—such matter must, in many cases, be perfectly opaque, for in certain parts of the sky the stars are apparently entirely blotted out. It is hard to believe in the existence of such matter on such a tremendous scale as is implied by the photographs. As to its nature if it does exist, it must in some way be related to the nebulae, for we find them in most cases to be intimately connected. Is it an ultimate condition of nebulous matter or is it something wholly different from the ordinary nebulosity of the sky?

To those who may be interested in the subject of possible masses of dark absorbing matter in space in connection with visible nebulosities I would refer to a paper of mine, "On a Nebulous Groundwork in the Constellation *Taurus*," *Astrophysical Journal*, **25**, 218, April 1907, where a system of dark lanes and holes in *Taurus* is shown to exist in the sky independently of the stars.

The accompanying photographs were made by me with the 10-inch Brashear lens of the Bruce photographic doublet which, through the courtesy of Professor Hale, was temporarily stationed at the Solar Observatory of the Carnegie Institution on Mount Wilson, California, in 1905.

As will be noticed in the photographs the great lane extending to the east from "the eye" on Plate II A and continued in Plate II B runs almost due east and west. While at the Lick Observatory,

I once showed a plate of this region to Professor Tucker, who had such a large part in the making of the *Cordoba Durchmusterung*. He said that this picture made clear an experience in his observing work at Cordoba that had always been a puzzle to him. One night he had set his telescope in the region a little north of *Antares* and prepared to record the transits of stars as they passed through the field. Presently no stars came into the field of his telescope. After watching for some time he finally concluded the sky had clouded over, but on looking out he found it perfectly clear. He returned and watched a long time before any stars appeared. His telescope had been pointed to this lane and nothing but blank sky had passed.

LIST OF STARS REFERRED TO ON THE CHART

Bonner Durchmusterung, EPOCH 1855.0

	No.	Mag.	α	δ
b	−18° 4240	7.5	16h 0m 39.s1	−18° 36.′4
c	−17 4502	6.5	16 1 34.4	−17 57.1
ν Scorpii	−19 4333	4.5	16 3 33.9	−19 4.4
d	−17 4511	7.3	16 3 40.6	−17 51.0
e	−21 4305	7.0	16 5 9.4	−21 1.5
f	−20 4444	6.8	16 5 56.9	−20 43.8
g	−20 4454	6.8	16 8 26.8	−20 56.2
h	−19 4357	6.0	16 10 38.3	−19 51.5
k	−19 4359	7.7	16 11 36.3	−19 41.9
l	−19 4361	7.3	16 12 0.8	−19 45.7
ψ Ophiuchi = m	−19 4365	5.0	16 15 37.3	−19 4.6

Cordoba Durchmusterung, EPOCH 1875.0

	No.	Mag.	α	δ	
χ Lupi	−33° 10754	4.2	15h 43m 1.s8	−33° 14.′7	
π Scorpii	−25 11228	3.4	15 51 18.0	−25 45.3	
δ Scorpii	−22 11292	2.7	15 52 57.1	−22 16.2	
13 Scorpii	−27 10841	5.3	16 4 36.6	−27 35.7	
σ Scorpii	−25 11484	3.4	16 13 37.2	−25 17.1	
	−24 12684	8.0	16 17 52.1	−24 10.3	The star with the 4 whorls
ρ Ophiuchi	−23 12861	4.8	16 18 6.1	−23 9.2	
Antares	−25 11359	1.4	16 21 46.0	−26 8.9	
22 Scorpii	−24 12695	5.5	16 22 37.6	−24 50.5	
n	−24 12698	9.3	16 24 7.4	−24 8.8	
τ Scorpii	−27 11015	3.2	16 28 6.8	−27 57.2	
p	−24 12765	6.3	16 34 2.4	−24 13.5	

YERKES OBSERVATORY
November 30, 1909

PRECAUTIONS NECESSARY IN PHOTOGRAPHIC PHOTOMETRY

By J. A. PARKHURST

In trying to get precise photometric results from stellar photographs, many sources of error have been encountered, some of which have not been thoroughly investigated. In the photometric work done at this observatory during the past five years, it has been found necessary not only to be on guard against unknown sources of error but also to ascertain the possible amounts of the errors arising from the better-known causes for the particular instruments, plates, and developers used. As the work progressed it became more and more evident that the plates contained precise data, which could be deduced by proper handling; a rough estimate of the accuracy possible was two to four times that found in the better class of visual work with photometric instruments. The present paper summarizes the investigations, much of the work being done in collaboration with Frank C. Jordan, while he was Fellow at this observatory.

COMPARISON OF DEVELOPERS

Pairs of plates were exposed in a Scheiner sector-machine and developed with hydroquinone, pyro, and rodinal. Fig. 1 shows specimens of the resulting development-curves obtained from measures of opacities in a Brace spectrophotometer as modified by Wallace for such work. In the figure the abscissas represent the logarithm of the light, calculated from the sector-angles. The ordinates are Hurter and Driffeld "density-units." It has been found (by means to be explained later) that on the straighter parts of these curves, one density-unit corresponds to about 1.7 stellar magnitudes. It follows from the figure that at log light=0.6, for example, the pyro curve lies above the rodinal curve by more than 0.3 magnitude, while the hydro curve is nearly 0.9 above the rodinal. Errors of such amounts might therefore arise from comparison of plates developed with different agents.

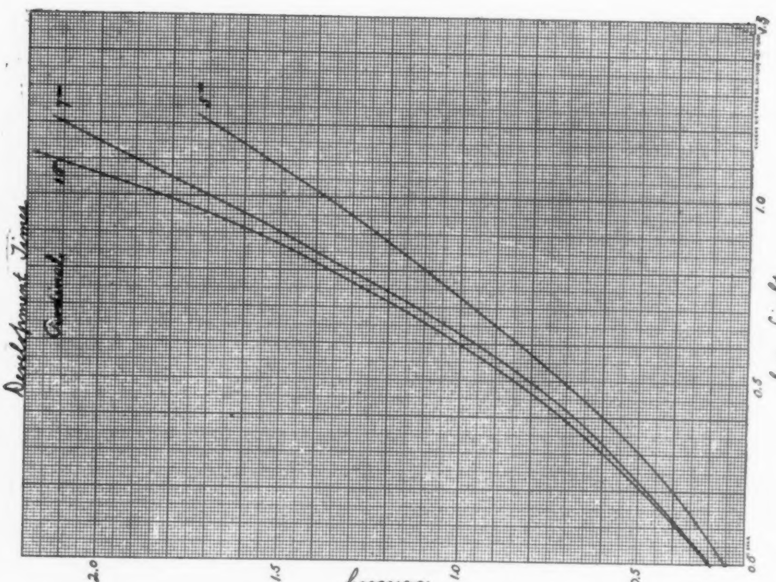


FIG. 2.—Time of Development

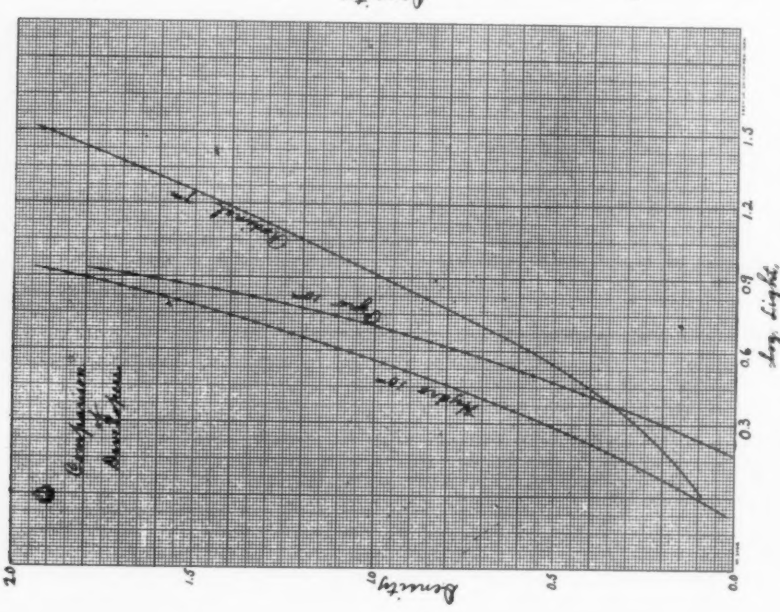


FIG. 1.—Comparison of Developers

TIME OF DEVELOPMENT

The effects of different development-times for Seed plates were tested for the three agents mentioned above. Fig. 2 shows sample curves for rodinal with 5, 7, and 10 minutes' development. Using the above-mentioned conversion factor, it will be seen from the curves that errors of 0.35 and 0.52 magnitude might arise from comparison of the 7 and 10 minutes' development, respectively, with the 5 minute; while on the denser images the difference might easily be double these amounts. In actual practice the development of our stellar plates, which is carried on in total darkness, is timed by an interval-timer which rings a bell after the interval for which it is set.

TEMPERATURE OF DEVELOPMENT

The effect of temperature was quite thoroughly investigated for the different developers and development-times. Fig. 3 shows the differences in light-effect on the Seed plates developed for 7 minutes with rodinal at 55° and 65° F. In this figure the ordinates are expressed in stellar magnitudes, which renders it easy to see the amount of the error possible from a range of 10° F. in the development-temperature—in this case 0.75 magnitude at log light = 1.5.

The literature of stellar photometry indicates that this point has frequently been neglected, or at least not sufficiently controlled. For example, King at Harvard,[1] in his standard tests of photographic plates, developed at "from 70° to 75° Fahrenheit," though his notes show the temperature of the developing room to have been as high as 87° F.[2] It is evident that such ranges are sure to introduce considerable errors, and it seems conservative to put the maximum allowable range as less than one degree F. in order to keep the outstanding errors within 0.05 magnitude. At this observatory the photometric plates are developed with hydroquinone in a tank at 20° C. for ten minutes, thus keeping the above-mentioned factors under close control.

EFFECT OF SKY-FOG, OR SUPPLEMENTARY EXPOSURE

With the extra-focal plates used for determining absolute photographic magnitudes,[3] the effect of sky-fog on the fainter images was

[1] *Harvard Annals*, **59**, 3. [2] *Ibid.*, **59**, 14.

[3] *Astrophysical Journal*, **26**, 244, 1907.

very marked. Fig. 4 shows in the full line the reduction-curve found for the plates used, where the film was clear (scale-reading not above 7), while the dotted line shows the curve needed where the sky-fog was enough to give a scale-reading of 10. The actual difference between these film readings is only 0.03 of a density-unit, but the

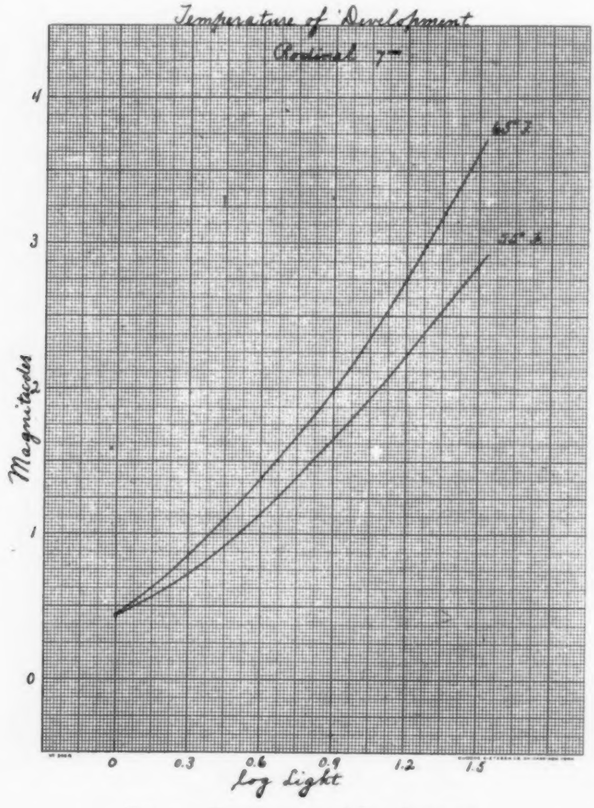


FIG. 3.—Temperature of Development

error caused by neglecting it would amount to 0.6 magnitude at scale-reading 12. Errors of similar amounts will be found in the measurement of the diameters of focal images, since the sky-fog will strengthen the penumbra around the fainter stars to an appreciable extent. This will be especially marked on refractor plates, but the effect cannot be neglected even on plates taken with a reflector, where the penumbra is weaker.

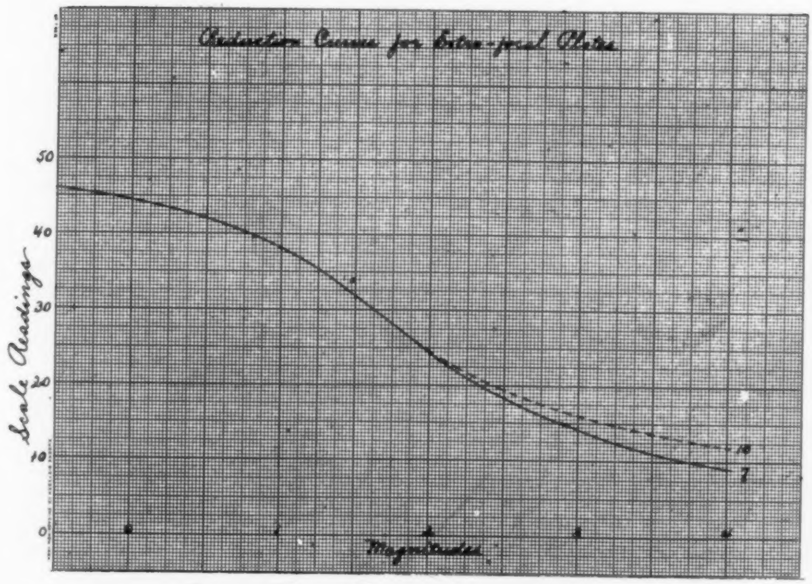


FIG. 4.—Effect of Sky-Fog on Reduction-Curves

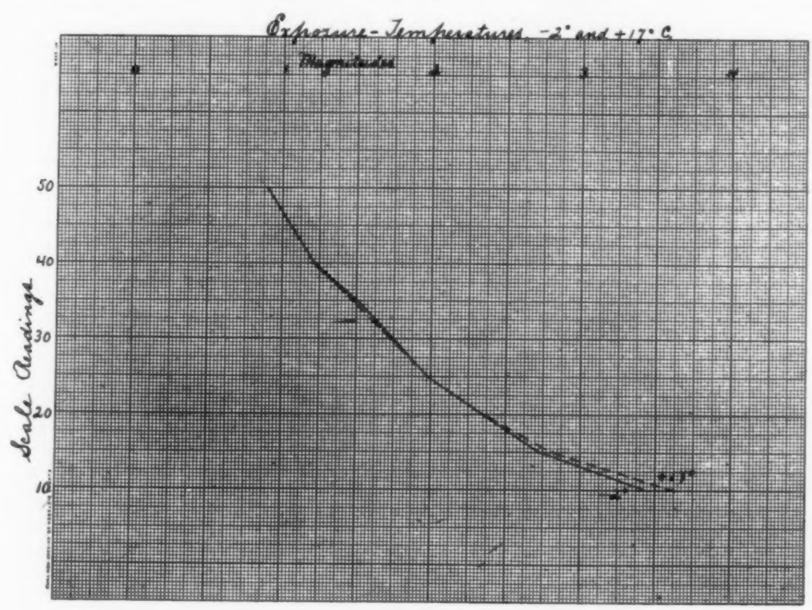


FIG. 5.—Temperature of Exposure

EXPOSURE-TEMPERATURE

Tests were made of the effect of exposure-temperatures ranging from $-2°$ to $+17°$ C. Fig. 5 shows the curves platted from two plates at the extreme temperatures. These plates were exposed in a sensitometer box and measured with the Hartmann "Mikrophotometer" which is described in the *Astrophysical Journal* article last quoted. In the figure measured points are connected by straight lines (as the scarcity of data does not warrant the drawing of a curve) and show that the effect of temperature is not evident within the measured portion of the plates, which did not include the dense and thin extremes.

LACK OF UNIFORMITY IN THE PHOTOGRAPHIC FILM

This is quite certain to be present if the film is irregular in thickness, and may also arise from differences in sensitiveness. The Seed and Cramer plates used, $3\frac{1}{4}\times4\frac{1}{4}$ and 4×5 inches in size (8×11 and 10×12.5 cm), were cut at the factory after coating, from larger plates. The film within half an inch of the edge of the original large plate is usually thinner than the rest, enough so to introduce errors as large as half a magnitude; agreeing with Hartmann's[1] investigations. No such errors were found near the cut edges of the small plates, but as it is usually impossible to tell which are the cut edges, all the edges were discarded. The small "local errors" remaining are checked by measures of the unexposed film near each star-image. A consideration of several hundred such measures showed that the variations seldom exceeded 0.2 mm in the scale-reading of the Hartmann photometer used with the extra-focal plates. The maximum effect on the star-magnitudes is 0.1 in the most unfavorable case, and would seldom exceed 0.04 for the stars measured. If the variation in the film was greater than 0.3 mm the star was rejected. These errors are much smaller than might be expected on commercial plates, and seem to justify their use, rather than those coated on plate-glass, which are not on the market in this country.

[1] "Ueber die Konstanz der Empfindlichkeit innerhalb einer photographischen Platte," Eder's *Jahrbuch für Photographie*, 1906.

CURVATURE OF THE SURFACE

The commercial plates of the above-mentioned makers are usually coated on the concave side. Measures of a large number of plates made with the feet of the spherometer 48 mm from the screw, showed a concavity ranging from 0.05 to 0.14 mm, the uncertainty being usually less than 0.04. This is about the uncertainty in focusing. It would have no appreciable effect on the magnitudes from the extra-focal plates, and would seldom introduce errors greater than 0.01 or 0.02 magnitude on the focal plates.

REDUCTION FORMULAE FOR FOCAL PLATES

Two reduction formulae have been in common use, the logarithmic and the square root. The former,

$$\text{Mag.} = a - b \log D,$$

where D is the disk-diameter, and a and b are constants determined for the plate, is given by Scheiner in his *Photographie der Gestirne*. The other,

$$\text{Mag.} = a - b\sqrt{D},$$

is used at Greenwich and at other English observatories. Fig. 6 shows how well the two formulae fit the reflector and doublet plates taken here. The platted points are from measures of *Pleiades* plates, using magnitudes determined by the extra-focal method, and agreeing with Schwarzschild's photographic magnitudes. In the upper part of the figure are platted in round dots the square-roots from the co-ordinates given at the top and right. In the lower part, the crosses represent the logs of the same diameters, platted on a slightly smaller scale of abscissas. It is evident that the magnitudes are very well represented by the square-root formula. On the contrary, the use of the log formula would cause errors varying from half a magnitude to two or more magnitudes, according as the standards fell near the middle or the end of the curve. The conclusion is that the log formula cannot be used with the Seed or Cramer plates taken with the reflector or the Zeiss doublet (both kinds of plates gave the above result, also Cramer plates taken with the 40-inch refractor).

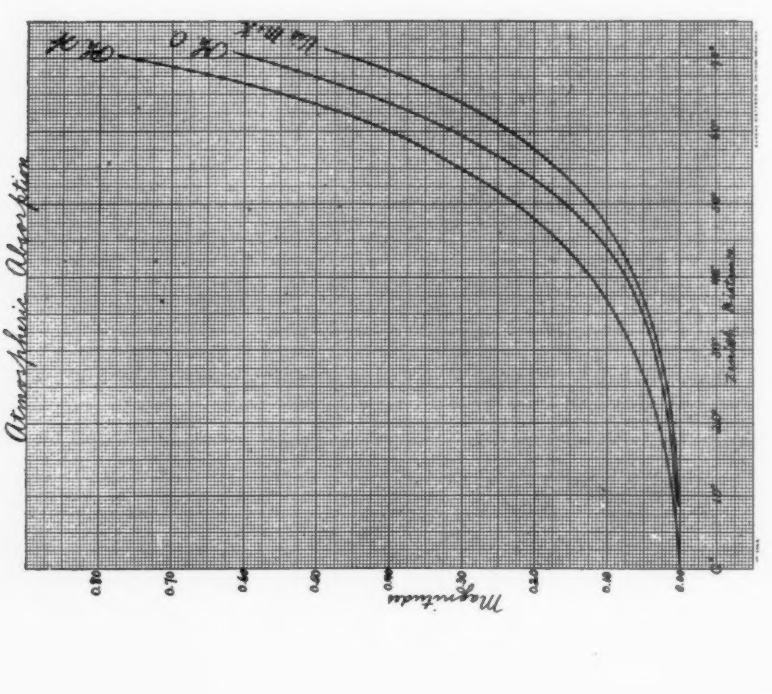


FIG. 7.—Atmospheric Absorption

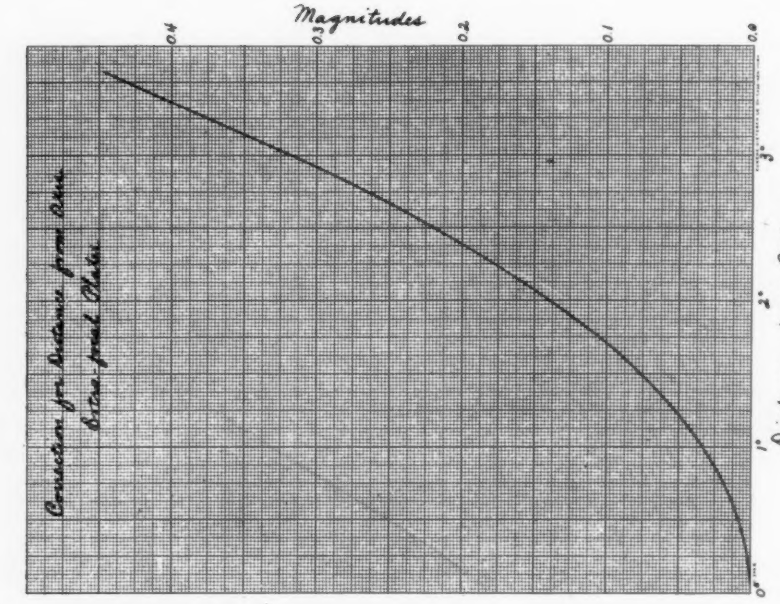


FIG. 8.—Correction for Distance from Axis on Extra-focal Plates

CORRECTION FOR ATMOSPHERIC ABSORPTION

The three curves drawn in Fig. 7 show the atmospheric absorption as far as 70° zenith distance. The lower curve, marked "Vis. M. & K.," gives the absorption of the visual rays from the Potsdam tables. These values were used with the plates taken with the "visual luminosity" filter, giving visual magnitudes. The second curve, marked "Ph. O.," gives the absorption of the photographic rays deduced by Oppolzer[1] from Schaeberle's measures of star images taken on Seed plates with a 6-inch Dallmeyer doublet. Oppolzer used the log formula in the reductions.

The third curve, marked "Ph. W.," gives the absorption determined by Wirtz[2] from extra-focal plates reduced with the "absolute" scale. This curve gives values of the absorption considerably greater than those found by Oppolzer, the probable reason being the use of the log formula by the latter, as our experience with the same brand of plates and similar doublets make the applicability of that formula very doubtful. The values given by Wirtz were therefore used here.

CORRECTION FOR DISTANCE FROM THE AXIS

The method used for finding this correction was by making uniform exposures on *Polaris*, moving the telescope by means of the declination screw between exposures. This gave a row of about 20 images across the axis of the lens. Measurements of these images with the corresponding distance from the center of the plate will give the correction-curve directly, *provided that the sky was uniform during the exposures*. The only possible control over this condition lies in a comparison of the curves from many different plates, as accidental errors, or temporary changes in the transparency of the air, will cause local deviations from the curve, while a progressive change in transparency will show by the inclination of the curve. The curve for extra-focal images, shown in Fig. 8, was drawn from the mean of 14 rows, rejecting those which were shown to be bad by the above criterion. This is the only part of the work where the time element enters. The plates were taken 6 mm inside the focus,

[1] "Photographic Extinction," *Sitzungsberichte der K. Akademie der Wiss. in Wien*, CVII, Abth. II, December 1898; also *Astrophysical Journal*, **9**, 317, 1899.

[2] *Astronomische Nachrichten*, **154**, 349, 1900.

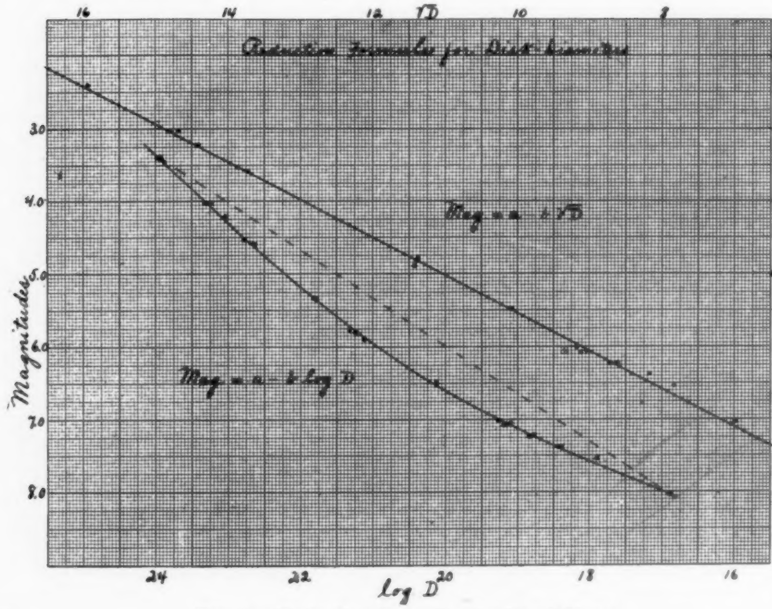


FIG. 6.—Reduction Formulae for Focal Plates

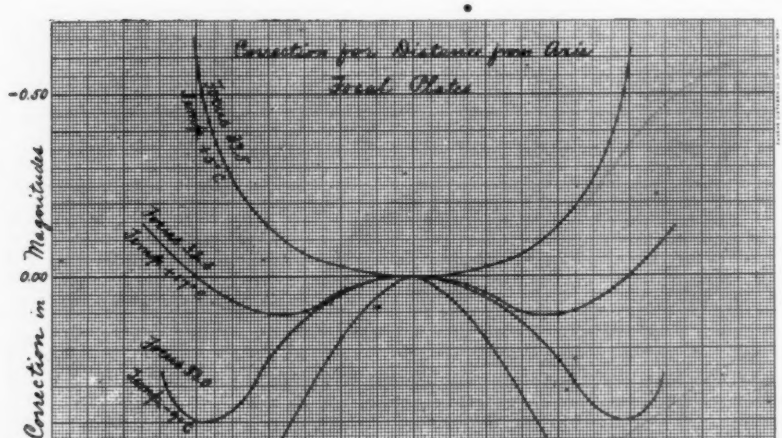


FIG. 9.—Correction for D'stance from Axis on Focal Plates

giving images 1.2 mm in diameter at the center of the plate. The correction at 3° from the axis amounts to 0.32 magnitude. Beyond this distance the measures are not very reliable.

Fig. 9 shows some of the correction-curves for focal plates taken with the Zeiss doublet at different focal settings and temperatures. The focal length of the doublet is 814 mm. The camera tube is brass, and has an inconveniently large expansion coefficient, giving a change of 1 mm for 34° C. The difference in the correction-curves for a change of 1 mm in the focus is shown by the upper and lower curves, made at settings 32.5 and 33.5. At three degrees from the axis the difference in the correction amounts to 1.4 magnitudes. This value applies only to these particular plates, which were taken through the "visual luminosity" filter and have very sharp images, the penumbra being almost absent. On plates taken without a filter, having more penumbra around the images, the actual amount of the correction would be different, perhaps more, perhaps less. The setting chosen for the focal plates was nearly that shown in the curve "Focus 32.5, Temp. +17° C." At this setting the maximum correction is at 2° from the axis, and an uncertainty of 0.05 mm in the setting would cause an error not exceeding 0.05 magnitude at 3° from the axis.

The ideal material for the camera tube would be "Invar," but whatever the material, the focal setting should correspond with the temperature within 0.05 mm for precise work.

YERKES OBSERVATORY
December 1909

THE SUN-SPOTS OF SEPTEMBER 25, 1909

By FREDERICK SLOCUM

As there is evidently some connection between terrestrial magnetism and solar activity, a statement in regard to observations of the sun about September 25, 1909, the date of the recent magnetic storm and auroral display, may be of interest.

The greatest disturbance of the magnetic storm, as reported by Mr. J. E. Burbank, of the magnetic observatory at Cheltenham, Md.,[1] lasted from $11^h\ 39^m$ A. M. to about 9^h P. M., G. M. T., September 25. The sun was observed here from 3^h to $8^h\ 30^m$, G. M. T., on that date. The most conspicuous feature on the disk was a large spot in latitude $-5°$, longitude 307°. At 4^h, this spot was 25° west of the central meridian of the sun. Visual observations showed the spot to be of a normal type, the umbra pear-shaped, about 29,000 km long, crossed by several bridges; the penumbra approximately circular, 38,000 km in diameter. Farther to the west, in latitude $-18°$ and $-16°$, longitude 320° and 329°, was a pair of small spots, connected by a stream of faculae, and to the north, in latitude $+18°$, longitude 333°, was an area of faculae without visible spot.

Calcium plates taken with the Rumford spectroheliograph, both before and after local noon, show a moderate amount of activity in the area around the large spot and in the region between the pair. Several eruptions are shown on the bridges and around the edge of the penumbra of the main spot, and four eruptions of considerable energy appear between the two spots of the pair. A series of five exposures, made in rapid succession just before noon, show no apparent difference, but a plate taken two hours after noon shows a new eruption on the northwest edge of the penumbra. Fig. 11 (Plate IV) is a portion of the morning plate, showing three of the five exposures, all of which were made on the same plate.

A prominence plate taken with the H line of calcium at $3^h\ 55^m$, G. M. T., shows a moderately large prominence in position-angle

[1] *Science*, **30**, 598, October 29, 1909.

PLATE III

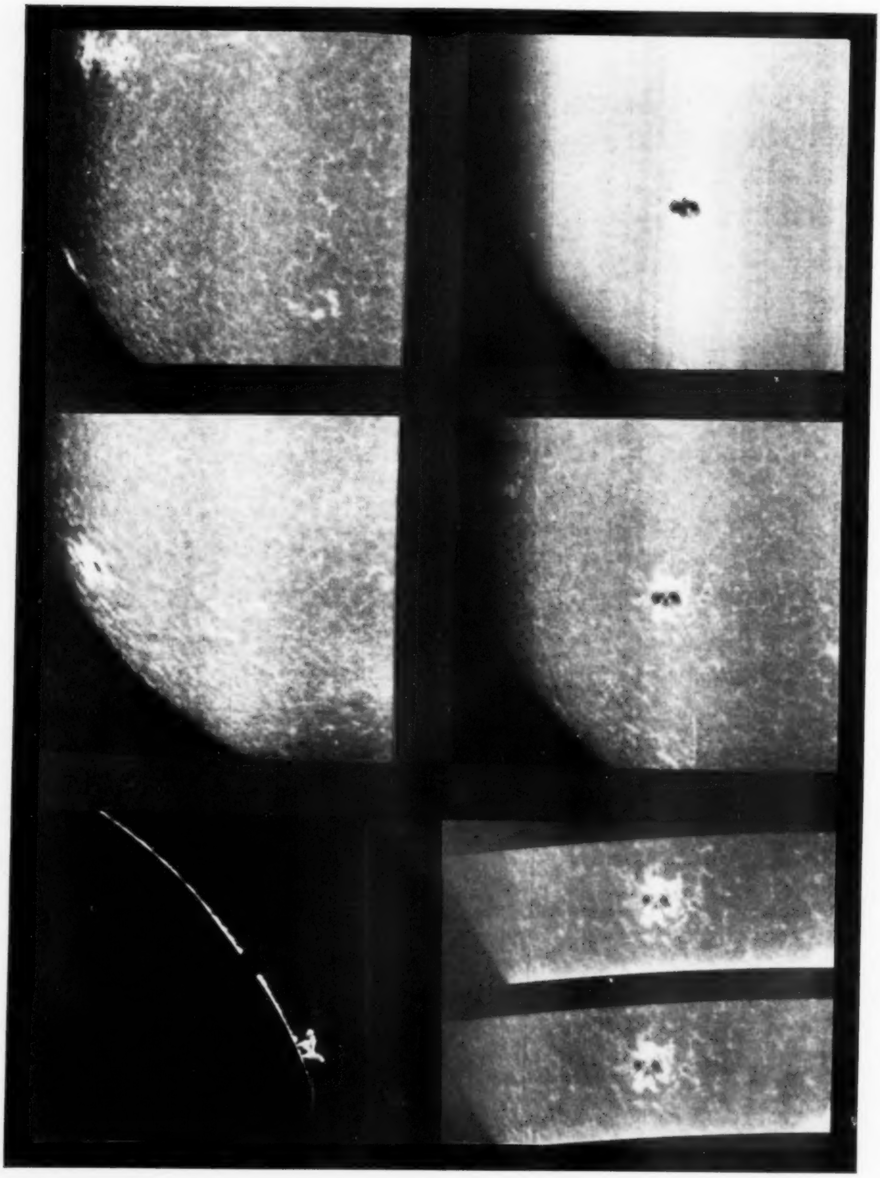
N

1
Sept. 17
$9^h\ 21^m.6$
G. M. T.
H_2

2
Sept. 18
$9^h\ 27^m.4$
H_2

E

3
Sept. 30
$10^h\ 57^m.3$
H_2



4
Sept. 20
$9^h\ 38^m.4$
G. M. T.
H_1

W

5
Sept. 20
$9^h\ 28^m.8$
H_8

6
Sept. 20
B $11^h\ 20^m.5$
H_2

A $11^h\ 19^m.5$
H_2

SPECTROHELIOGRAMS OF SUN-SPOTS
1909, September 17–20
Scale: Sun's Diameter = 140 mm

140°, which extends 8° along the limb and rises to an approximate height of 58,000 km. Eight other small prominences appear scattered around the edge of the sun.

These facts are mentioned simply to give an idea of the activity of the sun as a whole. If the sun is responsible for the great magnetic storm of September 25, it would seem as if the source of that disturbance must lie in the region of the great spot, on this date or earlier. A more detailed history of the spot will, therefore, be given.

The first trace of the spot was noted on September 1, when a small area of flocculi appeared near the western limb of the sun. This passed out of sight in a day or two, but reappeared on the eastern limb on September 17, Fig. 1 (Plate III). A prominence plate taken at 3^h 59^m, G. M. T., shows a small eruptive prominence in position-angle 118°, just over the northern edge of the spot. On September 18 the rotation of the sun had brought this region well into view, and it was at once noted that a good-sized spot had developed, Fig. 2. There are two umbrae, inclosed within a single penumbra, or perhaps it might be considered one umbra crossed by a broad heavy bridge. A chain of five or six eruptions extends along the northern edge of the preceding part of the umbra and down along the whole length of the bridge.

When the next observations were made, on September 20, a marked transformation had taken place. Figs. 3, 4, and 5 (Plate III) are taken from low, intermediate, and high-level calcium plates. The most interesting features of these plates are the broad bridges, one running from N. E. to S. W., the other from S. E. to N. W. On all three plates the latter seems to overlap and rest directly upon the former. Slight changes in the structure of these bridges are noted on plates taken only a few minutes apart. A few small eruptions are observed, particularly on the upper bridge and near its terminals, but these are neither as numerous nor as vigorous as on the 18th. On the H_2 plate, Fig. 6, the whole umbra appears veiled.

The spot passed the central meridian of the sun about 6^h, G. M. T., on September 23. Unfortunately no observations could be made on that date, but on the 24th, the plates show that the spot was still undergoing interesting changes. The high-level calcium flocculi over the spot present a marked spiral form, with several brilliant

eruptions on the branches and outside the spiral, Figs. 7 and 10. Subsequent observations showed that the spot maintained its activity. On the 25th it had lost its spiral structure but was crossed by several bridges, as noted above, Fig. 11. Plates of the 27th show a complete change in the arrangement of the bridges, with again a slight trace of spiral structure. They also indicate eruptions of considerable energy in various parts of the disturbed region.

No observations were obtained on the 28th or 29th. During the night of September 29–30, the spot passed around the western limb, and no trace of it could be seen visually on the morning of September 30, but its history was not yet completed. A prominence plate, taken at $3^h\ 48^m$, G. M. T., shows well several prominences of moderate size, and one small and inconspicuous jet at the point where the great spot disappeared. A second prominence plate, taken at $4^h\ 57^m$, G. M. T., shows that the spot was still active. Some time within the hour between the exposures of the two plates, a violent eruption had occurred. Where the one lone jet appears on the first plate is a brilliant prominence on the second plate, Fig. 3. In intensity, it is more brilliant than the chromosphere, a fine line of which appears on the prominence plate. It rises in several arches to a height of about 32,000 km, and extends some 5° or 6° along the limb. The observations of the next day, October 1, showed that this last violent eruption was still in progress. The spot had been carried some distance around the limb, but the tops of the arches of the prominence were still visible over the edge.

Two weeks later the spot appeared once more on the eastern limb. A long spell of cloudy weather seriously interfered with observations, but it was photographed on October 16, 18, 19, and 26. A companion spot had developed 2° south, and 7° east of the original spot, and both were inclosed by an extensive area of flocculi. Fig. 9 is taken from a low-level plate of October 19 and shows the spot nearly as it would appear in a direct view. Fig. 8 is from a high-level plate taken eight minutes earlier. This shows an extensive area of calcium flocculi with six eruptions following the leading spot and two just preceding the following spot. At the time of the brilliant auroral display of October 18, the spot was about 20° east of the central meridian.

PLATE IV

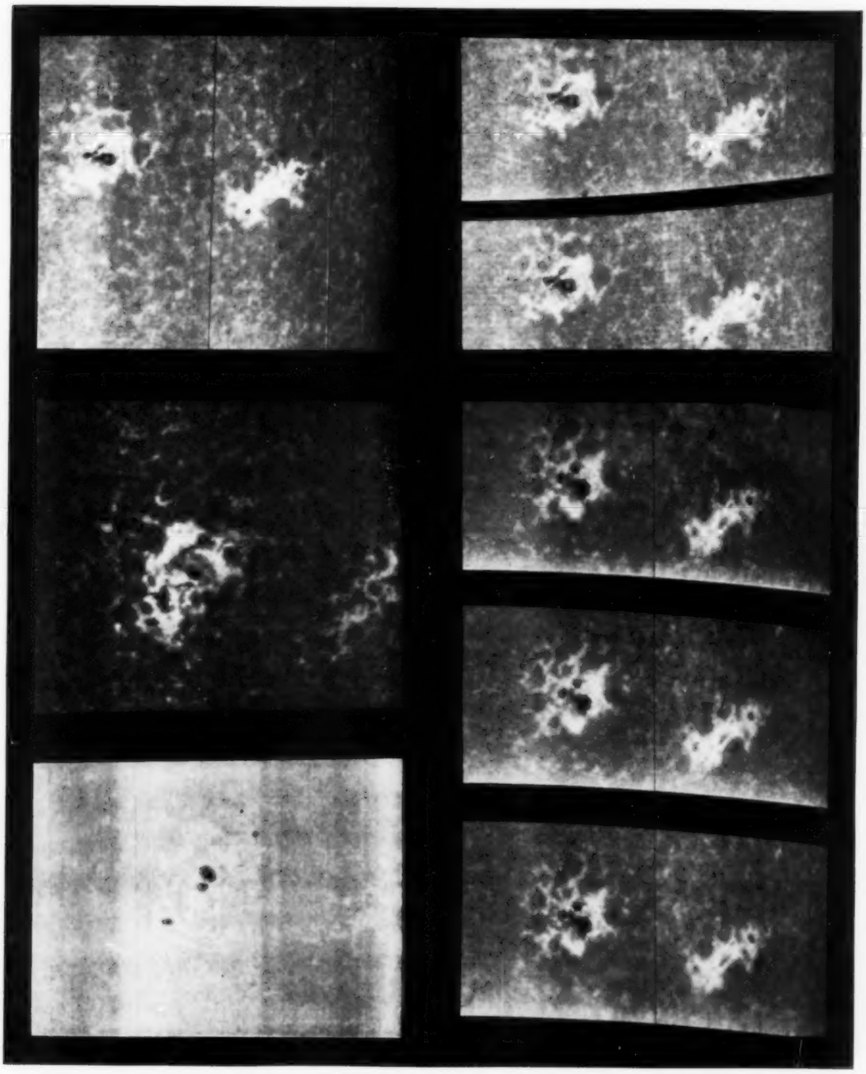
N

7
Sept. 24
$10^h\ 26^m7$
G. M. T.
H_2

8
Oct. 19
$9^h\ 22^m5$
H_2

E

9
Oct. 19
$9^h\ 30^m3$
H_1



10
Sept. 24
B $2^h\ 39^m6$
G. M. T.
H_2

A $2^h\ 38^m7$
H_2

11
C Sept. 25
$11^h\ 2^m0$
W H_2

B $11^h\ 1^m3$
H_2

A $11^h\ 0^m5$
H_2

Spectroheliograms of Sun-Spots
1909, September 24 and 25 and October 19
Scale: Sun's Diameter = 140 mm

On October 26, the spot could be seen very near the western limb of the sun and on the next day it had disappeared around the edge. On November 9 it appeared for the third time on the eastern limb, greatly diminished in area and activity. It was further observed on November 15 and 19. On the latter date it was apparently fast waning. There remained but a single small umbra and some scattered patches of calcium flocculi. This was the last seen of this interesting spot. It passed around the western limb a few days later, but failed to reappear on the eastern limb.

YERKES OBSERVATORY
December 9, 1909

AN INVESTIGATION OF THE DISPLACEMENTS OF THE SPECTRUM LINES AT THE SUN'S LIMB[1]

By WALTER S. ADAMS

In an important communication published in 1907, Halm announced the discovery of small displacements of the lines of the solar spectrum at the sun's limb which are independent of the motion of rotation.[2] The results of an investigation of two iron lines in the less refrangible part of the spectrum indicated a displacement toward the red of +0.012 Ångström as compared with their position at the sun's center. On the other hand, an enhanced line of iron at λ 6516 showed no displacement. The cause of these shifts Halm concluded to be the somewhat greater effective pressure in the sun's reversing layer at the limb than at the center, the lowest strata, which are subject to the greatest pressure, contributing a relatively greater length of path to the light at the limb than they do at the center. Halm accordingly explained the absence of displacement for the enhanced iron line by assigning it to a higher level in the sun's atmosphere. In such a case it is evident that the effect of the relative increase in the length of path of the light in the lower strata will affect the wave-length of the line but slightly.

A detailed study of these displacements was taken up by Mr. Hale and myself soon after the appearance of Halm's announcement, and one of our first results was the discovery that the whole solar spectrum is greatly changed in appearance at the sun's limb.[3] Three features were commented upon especially in connection with these results. First, the great weakening, and in some cases the almost complete disappearance of the wings shown by many of the strongest lines at the center of the sun. Second, a slight widening, which is characteristic of practically all of the lines in the spectrum, accompanied in most cases by a decided modification of their intensity-curves. Third, a strengthening and weakening of the lines which in

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 43.

[2] *Astronomische Nachrichten*, **173**, 273, 1907.

[3] *Contributions from the Mount Wilson Solar Observatory*, No. 17; *Astrophysical Journal*, **25**, 300, 1907.

general closely corresponds to that found in sun-spots. These main features of the spectrum of the sun's limb, together with some others, were summarized briefly in a later communication.[1] Some provisional results of the displacements measured were also given at the same time.

Recently MM. Buisson and Fabry undertook a comparison of the spectrum of the center and the limb of the sun with the aid of interference apparatus.[2] Their results relate to a region at about λ 4400, and give both the displacements and the widths of the lines observed. Perhaps their most important conclusion is that the displacements are due to the widening of the lines upon their red edges, the violet edges retaining their normal positions. This widening is ascribed by them to the relatively greater effect of pressure in the lower strata of the reversing layer, their explanation being identical with that of Halm.

The first plates obtained at Mount Wilson, and those upon which the results published by Mr. Hale and myself were based, were taken with the 18-foot spectrograph and the Snow telescope. These plates, though excellently suited for qualitative investigation of the character of the spectra and for relative displacements of the lines, were not well adapted for measurements of absolute displacements. This is evident from the fact that in order to pass from the center of the sun to the limb it was necessary to shift the image upon the slit, thus introducing a change in illumination of the grating, which could easily lead to systematic errors in the amount of the displacements upon the photographs. With the completion of the tower telescope the investigation was continued by myself with the 30-foot (9.1 m) spectrograph used in conjunction with it, and in order to avoid shifting the sun's image upon the slit a small diagonal prism attachment was designed to allow of photographing center and limb simultaneously. This is very similar to that used in the study of the chromosphere and described in a recent paper by Mr. Hale and myself,[3] except that opposite the central prism there are two small

[1] *Publications of the Astronomical Society of the Pacific*, **20**, 27, 1908.

[2] *Comptes Rendus*, **148**, 1741, 1909.

[3] *Contributions from the Mount Wilson Solar Observatory*, No. 41; *Astrophysical Journal*, **30**, 222, 1909.

openings through which the light from two regions of the sun symmetrical about the center falls directly upon the slit. The exposure upon the sun's limb is continuous, while that upon the center consists of a series of short exposures distributed throughout the entire exposure on the limb. This has, of course, the advantage of tending to eliminate possible effects of temperature variation during the exposure. The ratio of exposure time at the center to that at the limb varies greatly with the distance of the slit from the limb and with the region of the spectrum observed. On the average, a ratio of about 1 to 5 in the red to 1 to 15 in the ultra-violet is necessary to give equal intensities to the two spectra.

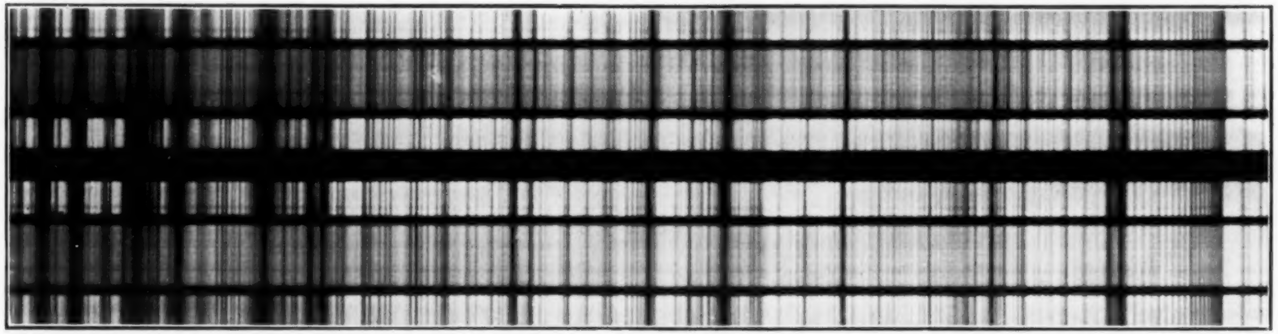
The plan followed in making the exposures has been to compare the spectrum of the center with that of the east limb and then with that of the west limb, the points selected lying at the extremities of the solar equator or at 0° of heliographic latitude. This, of course, introduces into the results the maximum displacements due to the rotation of the sun. These are readily eliminated, however, and the selection of points at the solar equator has two marked advantages. The first is that the change of the rotational velocity is smallest near the equator, so that slight errors in the setting of the instrument in position-angle have their least effect at this point. The second is that the measured displacements are large, and all positive at the west limb, and negative at the east limb. Judging from my personal experience in measuring displacements of this kind, they are much less liable to subjective error than small displacements of varying sign. It is clear that if δ is the displacement between center and west limb, and δ' the displacement between center and east limb, both taken without regard to sign,[1] $(\delta+\delta')/2$ and $(\delta-\delta')/2$ will be the displacements due to the rotation of the sun, and to pressure, respectively. The value of $(\delta+\delta')/2$ when converted into radial velocity should, of course, be constant for the different plates, and equal to the sun's equatorial linear velocity. This is about 1.86 km a second, uncorrected for reduction to the sun's edge or for the inclination of the sun's axis,[2] and corresponds to a linear displacement of 0.044 mm

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 24; *Astrophysical Journal*, **27**, 213, 1908.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 33; *Astrophysical Journal*, **29**, 110, 1909.

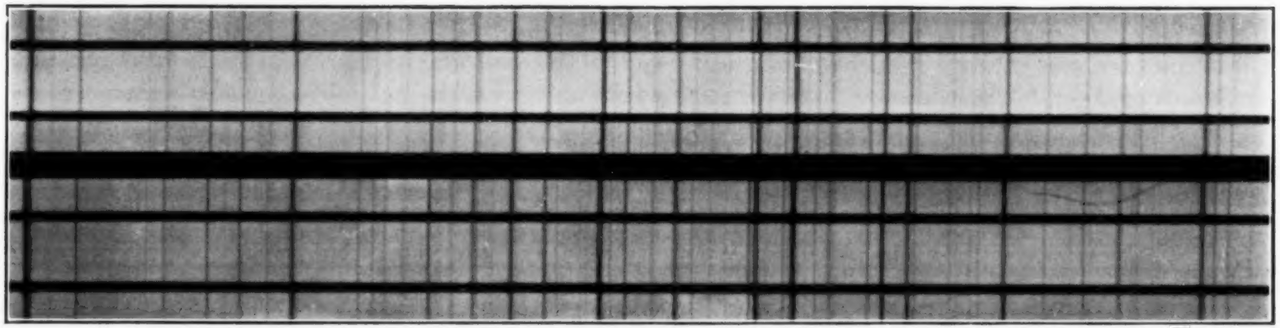
PLATE V

1
2



Region λ 3830–λ 3885

1
2



Region λ 5370–λ 5425

Spectra of Center and Limb of Sun

Scale: 1 Ångström = 3 mm, approximately

1. Center and West Limbs

2. Center and East Limbs

(at λ 4250) on the photographs in the third order of the 30-foot spectrograph. In the great range of wave-length covered by the measures given in this communication the linear value of $(\delta+\delta')/2$

Plate	Center of Region λ	Order	Observed $\delta+\delta'$	Computed $\delta+\delta'$	Rotational Velocity km
P 112	3818	3	0.086	0.080	1.94
P 155	3910	3	0.081	0.082	1.86
P 104	3940	3	0.084	0.083	1.91
P 133	3995	3	0.078	0.084	1.75
P 134	3995	3	0.084	0.084	1.89
P 114	4070	3	0.086	0.085	1.90
P 104	4110	3	0.088	0.086	1.92
P 135	4260	3	0.087	0.089	1.83
P 114	4300	3	0.094	0.090	1.95
P 103	4320	3	0.088	0.090	1.83
P 75	4320	3	0.094	0.090	1.95
P 95	4430	3	0.095	0.093	1.92
P 122	4430	3	0.092	0.093	1.86
P 147	4500	3	0.085	0.094	1.70
P 103	4520	3	0.089	0.095	1.77
P 89	4780	2	0.066	0.066	1.87
P 78	4780	3	0.100	0.100	1.88
P 105	4890	3	0.094	0.102	1.73
P 73	4980	3	0.103	0.104	1.86
P 73	4980	3	0.098	0.104	1.77
P 143	4980	2	0.069	0.069	1.88
P 106	5050	2	0.064	0.071	1.71
P 91	5250	2	0.075	0.073	1.92
P 106	5400	2	0.078	0.075	1.93
P 101	5400	2	0.079	0.075	1.96
P 84	5450	3	0.114	0.114	1.88
P 140	5480	3	0.113	0.115	1.84
P 91	5600	2	0.076	0.078	1.83
P 141	5670	3	0.109	0.118	1.73
P 101	5700	2	0.084	0.079	1.98
P 105	5770	2	0.084	0.081	1.96
P 115	5950	3	0.126	0.125	1.89
P 92	6050	2	0.086	0.085	1.93
P 100	6100	2	0.088	0.085	1.94
P 116	6100	3	0.133	0.128	1.96
P 105	6140	2	0.089	0.086	1.95
P 116	6240	3	0.132	0.131	1.91
P 92	6400	2	0.094	0.089	1.98
P 100	6420	2	0.086	0.089	1.80
P 124	6420	2	0.083	0.089	1.74
P 139	6420	2	0.085	0.089	1.79
P 100	6420	2	0.091	0.089	1.91

corresponding to a velocity of 1.86 km varies from 0.040 mm to 0.068 mm. The constancy of the value of $\delta+\delta'$ when reduced to velocity has furnished an extremely valuable check upon the observations and the adjustment of the instrument. In the present discus-

sion no plates have been included for which this value has differed from the theoretical value to an extent beyond the reasonable limits of accidental error, but among all the plates taken since the attachment for obtaining the spectra of center and limb simultaneously has been employed only three have been discarded for this cause.

The following table contains a list of the plates employed in this discussion. The second column gives the mean wave-length of the lines measured, the fourth column the corresponding values of $\delta + \delta'$, the fifth column the theoretical values based on a value of 0.088 mm for λ 4250, and the last column the observed values of $(\delta + \delta')/2$ reduced to radial velocity. The mean of all the plates gives a determination of the sun's equatorial rate of rotation which is of considerable weight, although inferior to one obtained from the same number of plates in which the spectra of the two limbs are compared directly. The value obtained from the mean of all the plates is 1.87 km as compared with about 1.86 km found from the investigation of the rotation of the sun during 1908.

The selection of the lines to be measured upon these plates was a subject which gave rise to a considerable amount of difficulty on account of the large number of questions involved. The great variety in the behavior of the lines of different elements at the sun's limb, the wide range of level attained by various gases in the solar atmosphere, the abnormal behavior of the enhanced lines, as well as the necessity of including a sufficient number of lines in different parts of the spectrum to furnish material for a discussion of the change of displacement with wave-length, all made it difficult to keep the list within reasonable limits. Finally a total of 470 lines was selected, ranging in wave-length from λ 3741 to λ 6573. This list includes:

1. All prominent enhanced lines.
2. All lines of calcium, magnesium, and sodium.
3. The measurable lines in the cyanogen flutings.
4. The α and γ lines of hydrogen.
5. The measurable lines of elements of very high atomic weight, such as lanthanum and cerium.
6. A large number of lines of iron, titanium, vanadium, chromium, and other elements, distributed as uniformly as possible throughout the spectrum.

7. Lines especially strengthened or weakened in the spectrum of the sun's limb.

In the list of these lines which follows, the mean values of the displacements are given, it being impossible within the limits of this discussion to give the individual values for the different plates. The first three columns of the table give the wave-lengths, intensities, and identifications of the lines as taken from Rowland's table. The fourth column gives the intensity and behavior of the lines at the limb. The widening, indicated by "w," is on a scale of 1 to 3, "w_1" representing a comparatively small amount. As is well known, in the case of winged lines, the wings are greatly reduced at the limb. This behavior is indicated by the abbreviation "sh" for "sharpened," the degree to which this takes place being indicated by the subscripts 1, 2, and 3. The fifth column contains the number of measures, and the sixth column, Δ, the mean displacement in Ångström units. It is, of course, equivalent to the quantity $(\delta-\delta')/2$, referred to earlier in this discussion, converted into Ångström units. The positive sign, as usual, denotes displacement toward the red.

The seventh column, Δ', requires discussion. It was found early in the series of measures that an occasional plate which gave a correct value for the rotational velocity would give considerably larger values for the displacements at the limb than did the majority of the plates. This applies as well to the lines in the cyanogen flutings at λ 3883 and λ 4216, which were shifted by small amounts toward the red. If, however, a correction was applied to these lines to reduce their shifts to zero it was found that the values for the other lines agreed satisfactorily with those obtained from the remainder of the plates. As is well known, the cyanogen flutings are not shifted by pressure, at least to any appreciable extent. In fact, the only cause with which we are familiar that is adequate to produce displacements of fluting spectra is motion in the line of sight. Accordingly, since instrumental sources of error for these plates are made extremely improbable by the fact that correct values for the sun's rotational velocity are given by them, the conclusion seems practically inevitable that they are affected by currents in the sun's reversing layer, giving rise to small motions in the line of sight. In the case of cyanogen, the average displacement toward the red of 14 lines in the ultra-violet

fluting for the plate showing the largest discrepancies amounts to 0.003 Ångström. A current in the reversing layer at the center of the sun which is ascending at a rate of 0.12 km a second, or sufficient to produce a displacement of 0.0015 Ångström, would be adequate to explain this result. Since the convection currents in the solar atmosphere are almost certainly directed radially, small upward motions at the sun's center are rendered very probable by considerations quite apart from those discussed here. The largest difference of this kind encountered upon any of the plates is in the case of P106 for which the center of the spectrum falls at about λ 5400. The difference from the mean in this case amounts to +0.006 Ångström. This would indicate a motion of ascent at the sun's center of 0.23 km a second.

It has seemed desirable to show the results of a correction for this effect upon the observed displacements. This has been done by obtaining from the mean of the cyanogen lines in the ultra-violet fluting, measured upon all the plates and given under Δ in the table, a value of the correction necessary to reduce their displacements to zero, and applying it throughout the spectrum. The value obtained was 0.0020 Ångström, and this quantity, increased in proportion to wave-length, has been subtracted from all of the measured displacements. The results are given in the column Δ'. It is, of course, evident that this procedure is not strictly correct, since the plates in the different parts of the spectrum were not all taken at the same time as the plates containing the cyanogen flutings, and hence are not subject necessarily to the same correction. Since, apart from the cyanogen lines, however, we have no standards for reference, it has seemed best to apply this value as giving at least a reasonable approximation to a mean condition. In the discussion of the results, both the directly observed values, Δ, and the corrected values, Δ', will be considered.

Before taking up the more extended discussion of these results and the question of pressure as the effective agent in producing them, I wish to call attention to some of the prominent characteristics of the list which are evident from a simple inspection.

1. The lines of hydrogen, the H and K lines of calcium, λ 4227 of calcium, the D lines of sodium, and the *b* lines of magnesium

λ	Substance	Intensity	Intensity at Limb	No. of Meas.	Δ	Δ′	Remarks
3741.791	*Ti*	4	3	2	+0.006	+0.004	Enhanced line of *Ti*
3748.144	*Ti*	1	0	2	+0.001	−0.001	Enhanced line of *Ti*
3748.408	*Fe*	10	sh_2	2	+0.002	0.000	
3753.003	*Ti*	4	w_1	2	+0.002	0.000	
3757.824	*Cr–Ti*	4	3	2	+0.003	+0.001	Enhanced line of *Ti*
3759.447	*Ti*	12d?	$8sh_1$	2	+0.003	+0.001	Enhanced line of *Ti*
3760.679	*Fe*	4	w_1	2	+0.005	+0.003	
3762.012	*Ti*	3	$2w_1$	2	+0.004	+0.002	Enhanced line of *Ti*
3774.473	*Y*	3	$2w_1$	2	+0.001	−0.001	
3774.971	*Fe*	4	w_1	2	+0.004	+0.002	
3775.717	*Ni*	7	w_1	2	+0.005	+0.003	
3778.203	*Ni*	2	$3w_1$	2	+0.004	+0.002	
3778.939	*CN*	1	0–1	2	+0.002	+0.001	
3783.674	*Ni*	6	6	2	+0.006	+0.004	
3791.246	*CN*	0	0	2	+0.002	0.000	
3792.824	—	2	1	2	+0.009	+0.007	
3801.5	*CN*	2	$0–1w_1$	2	0.000	−0.002	
3806.357	*Fe–CN*	2	$1w_1$	3	+0.007	+0.005	
3815.038	*CN*	0	000	3	0.000	−0.002	
3817.059	*Co*	1	0	3	+0.005	+0.003	Enhanced line of *Co*
3818.759	*CN*	1	0–1	3	+0.004	+0.002	
3829.501	*Mg*	10	$sh_3\ w_2$	3	−0.002	−0.004	
3832.450	*Mg*	15	$sh_3\ w_2$	3	0.000	−0.002	
3834.364	*Fe*	10	$8sh_2$	3	+0.004	+0.002	
3836.229	*Ti*	2	1–2	4	+0.004	+0.002	Enhanced line of *Ti*
3836.66	*CN*	2d	1	4	+0.004	+0.002	
3842.191	*Co*	3	$2w_1$	4	+0.010	+0.008	
3843.854	*Co*, —	2d	1	4	+0.006	+0.004	Enhanced line of *Co*
3844.378	*CN*	4d?	$3w_1$	4	+0.002	0.000	
3846.131	*CN*	2	1	4	+0.005	+0.003	
3846.554	*Fe*	2	1–2	4	+0.005	+0.003	Enhanced line of *Fe*
3855.989	*V*	4	2	4	+0.006	+0.004	
3863.533	*CN*	3N	$2w_1$	4	0.000	−0.002	
3864.438	*CN*	3	$4w_2$	5	+0.004	+0.002	
3865.005	*V*	3Nd?	$2w_1$	5	−0.001	−0.003	
3866.960	*CN–V*	2	$1w_2$	5	+0.003	+0.001	Enhanced line of *V*
3868.539	*CN*	1	$0w_1$	6	0.000	−0.002	
3871.963	*Fe*	2	1–2	5	+0.008	+0.006	Enhanced line of *Fe*
3880.87	*CN*	2	$1–2w_2$	6	+0.004	+0.002	
3881.78	*CN*	2	$1w_2$	5	+0.003	+0.001	
3882.650	*CN*	1	0	5	−0.001	−0.003	
3895.119	*Co*	3	$4w_1$	6	+0.002	0.000	
3900.681	*Ti–Fe*	5	4–5	6	+0.008	+0.006	Enhanced line of *Ti*
3902.002	*Nd–*	3	1	5	+0.006	+0.004	
3904.926	*Ti*	3	2	6	+0.002	0.000	
3905.660	*Si*	12	$8sh_3$	6	+0.004	+0.002	Possibly enhanced line of *Cr* falls here
3906.044	*Nd–*	3N	1	6	+0.010	+0.008	
3913.609	*Ti–*	5d?	w_1	6	+0.006	+0.004	Enhanced line of *Ti*
3916.545	*V*	3	2–3	6	+0.008	+0.006	Enhanced line of *V*
3920.410	*Fe*	10	$9sh_2$	6	+0.006	+0.004	
3921.563	*Ti*	1	2	5	+0.002	0.000	
3921.695	*La–*	4	1	6	+0.008	+0.006	

λ	Substance	Intensity	Intensity at Limb	No. of Meas.	Δ	Δ′	Remarks
3924.673	*Ti*	4	4	6	+0.006	+0.004	
3926.597	*Mn*	2n	1	6	+0.009	+0.007	
3933.825	*Ca*	1000	w_3 sh_3	5	+0.001	−0.001	Central absorption line measured
3941.878	*Co*	3	w_1	6	+0.005	+0.003	
3944.160	*Al*	15	w_1 sh_3	4	+0.001	−0.002	
3948.818	*Ti, V*	4	4	5	−0.001	−0.003	
3950.102	*Fe*	5	$6w_1$	5	+0.006	+0.004	
3950.497	*Y*	2	2	5	+0.004	+0.002	
3954.002	*Fe–*	3	4	5	+0.005	+0.003	
3956.819	*Fe*	6	5	5	+0.007	+0.005	
3958.073	*Co*	2	$3w_1$	5	+0.002	0.000	
3961.674	*Al*	20	w_1 sh_3	5	+0.003	+0.001	
3962.995	*Ti*	3	3	5	+0.003	+0.001	
3968.625	*Ca*	700	w_3 sh_3	3	0.000	−0.002	Central absorption line measured
3977.891	*Fe*	6	5	5	+0.006	+0.004	
3984.294	*Mn*	2	$1–2w_1$	5	+0.005	+0.003	
3987.755	*Ti?*	2	$2–3w_1$	5	+0.006	+0.004	Enhanced line of *Ti*
3988.6	*La*	1	0	3	+0.002	0.000	
3994.828	*Nd?*	2	$1w_1$	6	+0.006	+0.004	
3995.463	*Co*	5	$6w_1$	6	+0.006	+0.003	
3995.899	*La*	1nd?	00	5	+0.002	0.000	
3996.140	*Fe*	3	3	6	+0.005	+0.003	
3997.258	*Cr? V*	1	1–2	6	+0.007	+0.005	
3998.790	*Ti*	4	4	6	+0.006	+0.004	
4003.912	*Ce–Fe–Ti*	3	3	6	+0.001	−0.001	
4005.408	*Fe*	7	$6sh_2$	6	+0.008	+0.006	
4005.856	*V*	3	$2–3w_1$	6	+0.005	+0.003	Enhanced line of *V*
4007.429	*Fe*	3	$4w_1$	6	+0.006	+0.004	
4012.541	*Ti, Ce*	4	$3w_1$	5	+0.004	+0.002	Enhanced line of *Ti*
4014.420	*Fe*	1	2	5	+0.005	+0.003	
4015.760	*Ni*	3	2–3	5	+0.006	+0.004	Enhanced line of *Ni*
4018.25	*Mn*	7	$6w_1$	5	+0.005	+0.003	
4022.018	*Ti–Fe–V*	5d?	4	5	+0.009	+0.007	
4023.533	*V, Co*	3	w_2	5	+0.005	+0.003	Enhanced line of *Co*
4024.726	*Ti*	3	4	5	+0.005	+0.002	
4025.286	*Ti–Ce*	3	3	5	+0.007	+0.005	Enhanced line of *Ti*
4028.497	*Ti–Ce*	4	3	5	+0.004	+0.002	Enhanced line of *Ti*
4034.644	*Mn–*	6d	$5sh_1$	5	+0.006	+0.004	
4035.883	*Mn*	4d?	3	5	+0.007	+0.005	
4041.803	*Zr–*	1	1	5	+0.005	+0.003	
4044.294	*K*	0	1	5	+0.005	+0.003	
4047.461	*Ce–Fe*	2	w_1	4	+0.007	+0.005	
4049.482	*Fe*	2	$2–3w_1$	4	+0.006	+0.004	
4053.981	*Cr–Fe–Ti*	3	w_1	4	+0.006	+0.004	Enhanced line of *Ti*
4055.701	*Mn–Fe*	6	w_1	4	+0.006	+0.004	Enhanced line of *Fe*
4058.748	*Ce*	0	0	4	+0.003	+0.001	
4059.081	*Mn*	3	w_2	4	+0.007	+0.005	
4060.415	*Ti*	1	1–2	3	+0.003	+0.001	
4061.244	*Nd–*	3	2	4	+0.007	+0.005	
4063.759	*Fe*	20	$18sh_3$	4	+0.008	+0.006	
4070.431	*Mn*	3	w_1	4	+0.006	+0.004	

λ	Substance	Intensity	Intensity at Limb	No. of Meas.	Δ	Δ′	Remarks
4083.095	*V–Mn*	4	w_1	4	+0.008	+0.005	
4086.861	*La*	1	0	4	+0.001	−0.001	
4095.094	*Ca?*	4	$3–4w_1$	4	+0.004	+0.002	
4103.097	*Si, Mn*	5	4	4	+0.009	+0.007	
4105.318	*V*	2	1	4	+0.004	+0.002	
4111.509	*Ce?*	1	0–1	4	+0.002	0.000	
4111.940	*V*	4	$3w_1$	4	+0.006	+0.004	
4112.869	*Ti*	1	2	4	+0.004	+0.002	
4115.330	*V*	3	w_1	4	+0.002	0.000	
4123.384	*La*	1	1	3	+0.001	−0.001	
4128.251	*Ce–V*, –	6d	$5w_1$	2	+0.006	+0.004	
4129.337	*Ce*–	3	2	2	+0.004	+0.002	
4130.804	*Ba*	2	0	2	+0.001	−0.001	
4137.809	*Ce*	1	0	4	+0.007	+0.005	
4144.038	*Fe*	15	$12sh_3$	4	+0.008	+0.006	
4165.759	–, *Ce*	1	1–2	4	+0.007	+0.005	
4167.884	*CN*	1N	0–1	4	+0.004	+0.002	
4171.213	*Ti*, –	4	3	5	+0.011	+0.009	
4172.066	*Ti, Fe*	2	$1–2w_1$	5	+0.007	+0.005	Enhanced line of *Ti*
4179.025	*Fe*	3	2	6	+0.009	+0.007	Enhanced line of *Fe*
4185.058	*Fe, Cr*	4	w_1	6	+0.006	+0.004	
4189.723	*CN*, –	2	w_1	6	+0.005	+0.003	
4196.699	*La*	2	1	6	0.000	−0.002	
4197.257	*CN*	2	2–3	6	+0.004	+0.002	
4202.198	*Fe*	8	$7sh_2$	6	+0.005	+0.003	
4203.730	*Cr*	2	$3w_2$	5	+0.005	+0.003	
4207.566	*CN*	1N	$0–1w_1$	6	+0.005	+0.003	
4212.801	*Cr?*	3N	$2w_2$	6	+0.009	+0.007	
4216.136	*CN*	1	$1–2w_1$	6	+0.003	0.000	
4220.509	*Fe*	3	$4w_1$	6	+0.008	+0.006	
4226.904	*Ca*	20d?	sh_1	6	+0.001	−0.001	
4232.887	*Fe*	2	3–4	6	+0.006	+0.004	
4233.328	*Mn–Fe*	4	3	6	+0.009	+0.007	Enhanced line of *Fe*
4233.772	*Fe*	6	$5sh_2$	6	+0.008	+0.006	
4238.970	*Fe*	5	4	6	+0.009	+0.007	
4240.872	*Cr*	1	1–2	6	+0.004	+0.002	
4254.505	*Cr*	8	sh_3	5	+0.005	+0.002	
4258.477	*Fe*	2	$4w_1$	5	+0.006	+0.004	
4260.640	*Fe*	10	sh_3	5	+0.004	+0.002	
4266.081	*Mn*	2	1–2	5	+0.006	+0.004	
4271.934	*Fe*	15	sh_3	5	+0.006	+0.004	
4274.958	*Cr*	7d?	$6sh_2$	5	+0.005	+0.003	
4281.530	*Ti*	0	1	5	+0.004	+0.002	
4282.565	*Fe*	5	$4–5sh_1$	5	+0.007	+0.005	
4283.169	*Ca*	4	$5sh_1$	5	+0.009	+0.007	
4284.382	*Cr*	2Nd?	0–1	5	+0.011	+0.009	Enhanced line of *Cr*
4287.566	*Ti*	1	$1–2w_1$	5	+0.006	+0.004	
4288.310	*Ti, Fe*	1	w_1	5	+0.008	+0.006	
4289.525	*Ca*	4	$4–5w_1$	5	+0.005	+0.003	
4289.885	*Cr*	5	sh_2	5	+0.007	+0.004	
4290.377	*Ti*	2	1–2	5	+0.007	+0.005	Enhanced line of *Ti*
4291.630	*Fe*	2	$3w_2$	5	+0.007	+0.005	
4294.936	*Zr*	2	2	5	+0.006	+0.004	

λ	Substance	Intensity	Intensity of Limb	No. of Meas.	Δ	Δ′	Remarks
4299.149	*Ca*	3	3	5	+0.006	+0.004	
4300.211	*Ti*	3	2	5	+0.008	+0.005	Enhanced line of *Ti*
4302.085	*Ti*	2	1	5	+0.012	+0.010	Enhanced line of *Ti*
4302.692	*Ca*	4	4–5sh$_1$	5	+0.005	+0.002	
4313.034	*Ti*	3	2	5	+0.004	+0.002	Enhanced line of *Ti*
4314.248	*Sc*	3	w$_1$	5	+0.004	+0.002	
4315.262	*Fe*	4	4	5	+0.008	+0.006	
4316.962	*Ti?*	1	0	5	+0.008	+0.006	Enhanced line of *Ti*
4318.817	*Ca, Mn?*	4	4–5sh$_1$	6	+0.005	+0.003	
4320.907	*Sc*	3	w$_2$	6	+0.003	+0.001	
4325.152	*Sc*	4	3	6	+0.004	+0.002	
4325.939	*Fe*	8	9sh$_3$	6	+0.003	+0.001	
4328.080	*Fe*	2	1–2	6	+0.003	+0.001	
4330.866	*Ti, Ni*	2	1	6	+0.008	+0.005	Enhanced line of *Ti*
4337.216	*Fe*	5	sh$_1$	6	+0.008	+0.006	
4338.084	*Ti*	4	3w$_1$	6	+0.004	+0.002	Enhanced line of *Ti*
4340.634	*H*	20N	15sh$_2$	6	+0.002	0.000	*Hγ* narrower at limb
4341.530	*Ti?*	2	1–2	6	+0.005	+0.003	Enhanced line of *Ti*
4344.451	*Ti–*	2	1–2	6	+0.005	+0.002	Enhanced line of *Ti*
4344.670	*Cr*	4	4–5	6	+0.005	+0.003	
4352.083	*Mg*	5Nd?	4sh$_2$	6	+0.004	+0.002	
4352.908	*Fe*	4	4	6	+0.006	+0.004	
4355.257	*Ca?*	2	1	6	+0.003	+0.001	
4376.107	*Fe*	6	6	10	+0.005	+0.003	
4378.419	–	2Nd?	w$_1$	10	+0.004	+0.002	
4379.396	*V*	4	3w$_2$	10	+0.005	+0.002	
4380.325	*Co*	2Nd?	1–2w$_2$	10	+0.004	+0.002	
4385.548	*Fe*	2	0	10	+0.013	+0.010	Enhanced line of *Fe*
4387.007	*Ti?*	1	0–1	8	+0.009	+0.007	Enhanced line of *Ti*
4387.220	–	1N	0–1	8	+0.006	+0.003	Possibly enhanced line of *Pb*
4395.201	*Ti*	3	2–3	8	+0.007	+0.005	Enhanced line of *Ti*
4399.935	*Ti, Cr*	3	2	8	+0.006	+0.004	Enhanced line of *Ti*
4400.555	*Sc*	3	w$_2$	8	+0.004	+0.002	
4415.722	–	3	2–3w$_2$	10	+0.006	+0.004	
4417.884	*Ti–*	3	w$_2$	10	+0.008	+0.005	Enhanced line of *Ti*
4425.608	*Ca*	4	sh$_1$	10	+0.004	+0.002	
4427.266	*Ti*	2	1–2	8	+0.004	+0.001	
4430.785	*Fe*	3	3	8	+0.008	+0.006	
4435.129	*Ca*	5	4sh$_1$	8	+0.006	+0.004	
4435.851	*Ca*	4	sh$_1$	8	+0.006	+0.004	
4441.881	*V–*	3Nd?	2–3w$_1$	8	+0.007	+0.005	
4442.510	*Fe*	6	5sh$_2$	8	+0.006	+0.004	
4443.365	*Fe*	3	w$_2$	8	+0.007	+0.005	
4443.976	*Ti*	5	4	8	+0.008	+0.005	Enhanced line of *Ti*
4447.892	*Fe*	6	5sh$_1$	8	+0.005	+0.003	
4449.313	*Ti*	2	1–2w$_1$	8	+0.005	+0.003	
4450.654	*Ti?*	2	2	8	+0.008	+0.006	Enhanced line of *Ti*
4453.486	*Ti*	2	w$_1$	8	+0.004	+0.002	
4454.552	*Fe*	3	3	8	+0.007	+0.004	
4456.794	*Ca*	2	2–3	8	+0.005	+0.003	
4461.818	*Fe*	4	5w$_1$	7	+0.007	+0.005	
4464.617	*Ti?*	2	w$_2$	7	+0.007	+0.005	Enhanced line of *Ti*

λ	Substance	Intensity	Intensity at Limb	No. of Meas.	Δ	Δ'	Remarks
4468.663	*Ti*–	5	4	7	+0.007	+0.005	Enhanced line of *Ti*
4469.316	*Ti*	1	1–2w₁	7	+0.004	+0.001	
4470.648	*Ni–Zr*	2	w₂	7	+0.007	+0.004	
4482.3	*Fe*, –	8	10w₂	6	+0.004	+0.002	
4489.911	*Fe*	4	6w₂	6	+0.007	+0.005	
4491.570	*Fe*	2	1w₁	6	+0.010	+0.008	Enhanced line of *Fe*
4494.738	*Fe*	6	5sh₁	6	+0.010	+0.007	
4497.023	*Cr*	3	w₁	6	+0.005	+0.003	
4501.445	*Ti*, –	5	4	6	+0.007	+0.005	Enhanced line of *Ti*
4508.455	*Fe*?, –	4	3	6	+0.011	+0.008	Enhanced line of *Fe*
4512.906	*Ti*	3	4	6	+0.004	+0.002	
4515.508	*Fe*	3	2	6	+0.011	+0.008	Enhanced line of *Fe*
4518.198	*Ti*	3	4	6	+0.004	+0.001	
4520.397	*Fe*?, –	3	2	6	+0.010	+0.008	Enhanced line of *Fe*
4522.802	*Fe*	3	1	6	+0.010	+0.008	Enhanced line of *Fe*
4522.974	*Ti*	2	2–3	6	+0.005	+0.003	
4527.101	*Ca*?	3	w₂	6	+0.007	+0.004	
4527.490	*Ti*	3	2–3	6	–0.004	–0.006	
4528.798	*Fe*	8	7sh₂	6	+0.005	+0.003	
4531.327	*Fe*	5	6	6	+0.007	+0.005	
4533.419	*Ti*	4	5	6	+0.005	+0.003	
4534.139	*Ti–Co*	6	5	6	+0.007	+0.004	Enhanced line of *Ti*
4534.953	*Ti*	4	w₁	6	+0.004	+0.001	
4536.094	*Ti*	2	1–2	5	+0.004	+0.001	
4546.129	*Cr*	3	4w₁	5	+0.007	+0.005	
4548.024	*Fe*	3	w₁	5	+0.008	+0.006	
4548.938	*Ti*	2	2–3w₁	5	+0.005	+0.003	
4549.642	*Fe*	2	0	5	+0.008	+0.006	Enhanced line of *Fe*
4549.808	*Ti–Co*	6d?	5	5	+0.005	+0.003	Enhanced line of *Ti*
4554.211	*Ba*	8	w₁	5	+0.008	+0.006	
4555.162	*Cr*	2	1	5	+0.009	+0.007	Enhanced line of *Cr*
4555.662	*Ti*	3	4w₁	5	+0.005	+0.003	
4556.063	*Fe*	3	1	5	+0.011	+0.008	Enhanced line of *Fe*
4558.827	*Cr*?	3	2	5	+0.009	+0.007	Enhanced line of *Cr*
4563.939	*Ti*	4	3–4	5	+0.008	+0.006	Enhanced line of *Ti*
4571.275	*Mg*	5	6w₁	5	+0.007	+0.005	
4572.156	*Ti*–	6	w₁	5	+0.007	+0.005	Enhanced line of *Ti*
4576.512	*Fe*	2	1	5	+0.009	+0.007	Enhanced line of *Fe*
4584.018	*Fe*–	4	2	5	+0.012	+0.009	Enhanced line of *Fe*
4586.047	*Ca*	4	3	5	+0.006	+0.003	
4586.552	*V*	1	0–1w₁	5	+0.007	+0.004	
4588.381	*Cr*	3	2–3	5	+0.010	+0.008	Enhanced line of *Cr*
4590.126	*Ti*	3	2–3	5	+0.008	+0.006	Enhanced line of *Ti*
4592.707	*Ni*	2	1–2	5	+0.005	+0.003	
4600.541	*Ni*	2	1–2	5	+0.006	+0.004	
4605.171	*Ni*	3	2	5	+0.009	+0.006	
4607.510	*Sr*	1	0–1w₁	5	+0.001	–0.001	
4679.409	*Ni*	2N	1–2w₁	2	+0.008	+0.006	Enhanced line of *Ni*
4680.317	*Zn*	1	0	2	+0.005	+0.003	
4682.088	*Ti*	3	4	2	+0.006	+0.004	
4686.395	*Ni*	3	2	2	+0.011	+0.008	
4703.177	*Mg*	10	8sh₂	2	+0.008	+0.006	
4703.994	*Ni*	3	2	2	+0.010	+0.007	

λ	Substance	Intensity	Intensity at Limb	No. of Meas.	Δ	Δ′	Remarks
4708.846	*Ti*	2	2	2	+0.008	+0.005	Enhanced line of *Ti*
4714.5	−*Ni*	7	5sh$_1$	2	+0.012	+0.010	
4715.946	*Ni*	4	4	2	+0.008	+0.005	
4722.342	*Zn*	3	2–3	2	+0.009	+0.007	
4729.864	*Fe? Cr*	1	1	2	+0.006	+0.004	
4733.779	*Fe*	4	w$_1$	2	+0.010	+0.007	
4736.963	*Fe*	6	5–6sh$_1$	2	+0.008	+0.006	
4737.817	*Fe?*	1	1–2	2	+0.004	+0.002	
4741.718	*Fe*	3	w$_1$	2	+0.008	+0.006	
4745.992	*Fe*	4	3–4	2	+0.009	+0.007	
4752.613	*Ni*	3	w$_1$	2	+0.006	+0.004	
4754.225	*Mn*	7	w$_1$	2	+0.006	+0.004	
4756.300	*Cr*	2	1	2	+0.008	+0.006	
4756.705	*Ni*	3	2–3	2	+0.008	+0.005	
4762.567	*Mn*	5	4–5sh$_1$	2	+0.007	+0.005	
4766.621	*Mn*	4	w$_1$	4	+0.007	+0.004	
4780.169	*Ti, Co*	2	1–2	4	+0.007	+0.004	Enhanced line of *Ti*
4783.613	*Mn*	6	w$_1$	4	+0.007	+0.005	
4787.003	*Fe*	2	2	4	+0.008	+0.005	
4789.849	*Fe*	3	w$_1$	4	+0.007	+0.005	
4810.724	*Zn*	3	2	4	+0.006	+0.004	
4823.697	*Mn*	5	w$_1$	4	+0.008	+0.005	
4841.074	*Ti*	3	3–4w$_1$	4	+0.004	+0.002	
4859.928	*Fe*	4	3–4	8	+0.009	+0.006	
4871.512	*Fe*	5	4	8	+0.009	+0.007	
4876.060	*Fe*	2	2	8	+0.007	+0.004	
4883.867	*Yt*	2	2	8	+0.004	+0.002	
4885.620	*Fe*	3	w$_1$	8	+0.009	+0.007	
4886.522	*Fe*	3	3	8	+0.008	+0.005	
4913.803	*Ti*	2	w$_1$	6	+0.005	+0.003	
4919.174	*Fe*	6	5	6	+0.009	+0.006	
4924.107	*Fe*	5	3–4	6	+0.009	+0.006	Enhanced line of *Fe*
4924.956	*Fe*	3	w$_1$	6	+0.008	+0.006	
4934.2	*Ba–Fe*	6	w$_1$	6	+0.014	+0.011	
4946.568	*Fe*	3	2–3	6	+0.009	+0.007	
4981.912	*Ti*	4	4–5	6	+0.006	+0.003	
4991.247	*Ti*	3	2–3	6	+0.004	+0.001	
4994.316	*Fe*	3	w$_1$	6	+0.008	+0.006	
4999.689	*Ti, La*	3	w$_1$	6	+0.006	+0.004	
5018.629	*Fe*	4	3	6	+0.008	+0.006	Enhanced line of *Fe*
5023.052	*Ti*	2	w$_1$	6	+0.006	+0.004	
5041.069	*Fe*	3d?	2	6	+0.006	+0.004	
5041.795	*Ca*	2	1	6	+0.003	+0.001	
5060.258	*Fe*	3	3	6	+0.010	+0.008	
5064.836	*Ti*	3	w$_1$	6	+0.008	+0.006	
5083.518	*Fe*	4	5w$_1$	9	+0.009	+0.006	
5084.279	*Ni*	3	2–3	9	+0.008	+0.005	
5087.601	*Y?*	1	0–1	5	+0.006	+0.003	
5097.175	*Fe, Cr*	3	2	5	+0.010	+0.008	Enhanced line of *Fe*
5103.142	*Ni*	1	2w$_1$	5	+0.005	+0.003	
5110.574	*Fe*	5d	5w$_1$	5	+0.012	+0.009	
5129.336	*Ti?*	3	2–3	5	+0.008	+0.006	Enhanced line of *Ti*
5131.942	*Ni*	1	w$_1$	5	+0.007	+0.004	

λ	Substance	Intensity	Intensity at Limb	No. of Meas.	Δ	Δ′	Remarks
5137.250	*Ni, Cr*	3	w$_2$	5	+0.007	+0.004	
5139.644	*Fe*	4	3sh$_1$	5	+0.007	+0.004	
5152.087	*Fe*	3	3–4w$_1$	5	+0.007	+0.005	
5154.244	*Ti–Co*	2	2	5	+0.007	+0.005	Enhanced line of *Ti*
5155.935	*Ni*	2	1–2w$_1$	5	+0.008	+0.005	
5159.231	*Fe*	2	1–2	3	+0.006	+0.004	
5166.454	*Cr–Fe*	3	4w$_1$	3	+0.012	+0.010	
5167.497	*Mg*	15	20sh$_3$	3	+0.002	−0.001	
5172.856	*Mg*	20	25sh$_3$	3	+0.001	−0.002	
5173.917	*Ti*	2	2–3	3	+0.006	+0.003	
5183.791	*Mg*	30	35sh$_3$	3	+0.001	−0.001	
5188.863	*Ti*	2	2	3	+0.004	+0.001	Enhanced line of *Ti*
5189.018	*Ca*	3	2	3	+0.008	+0.006	
5193.139	*Ti*	2	2–3	3	+0.005	+0.003	
5195.113	*Fe*	4	4–5w$_1$	3	+0.008	+0.005	
5197.743	—	2	1	3	+0.010	+0.007	Strong chromospheric line
5198.888	*Fe*	3	w$_1$	4	+0.007	+0.005	
5208.596	*Cr*	5	sh$_1$	4	+0.006	+0.004	
5210.555	*Ti*	3	3	5	+0.007	+0.004	
5225.695	*Fe*	2	3w$_1$	6	+0.008	+0.005	
5226.707	*Ti–*	2	1–2	6	+0.009	+0.007	Enhanced line of *Ti*
5234.791	—	2	1	6	+0.012	+0.010	Strong chromospheric line
5237.493	*Cr?*	1	0–1	6	+0.008	+0.005	Enhanced line of *Cr*
5247.737	*Cr*	2	3w$_1$	6	+0.007	+0.004	
5250.385	*Fe*	2	3	6	+0.008	+0.005	
5260.561	*Ca*	0	0–1w$_1$	4	+0.004	+0.001	
5265.729	*Ca*	3	3	7	+0.005	+0.003	
5284.281	*Ti*	1	0	9	+0.012	+0.009	Probably not *Ti*
5288.705	*Fe*	2	w$_2$	9	+0.009	+0.006	
5298.455	*Cr*	4	5w$_1$	9	+0.008	+0.005	
5316.790	*Fe*	4	2	9	+0.012	+0.009	Enhanced line of *Fe*
5333.089	*Fe*	4	4–5w$_1$	9	+0.010	+0.008	
5336.974	*Ti*, —	4	3–4	9	+0.011	+0.008	Enhanced line of *Ti*
5342.890	*Co*	1	0–1	9	+0.007	+0.004	
5348.511	*Cr*	4	w$_1$	9	+0.008	+0.005	
5349.653	*Ca*	4	4	9	+0.007	+0.004	
5367.669	*Fe*	6	5sh$_1$	11	+0.008	+0.006	
5377.800	*Mn*	2N	1–2w$_2$	11	+0.007	+0.004	
5381.221	*Ti*	2	2	11	+0.009	+0.006	Enhanced line of *Ti*
5394.87	*Mn*	2	3w$_2$	11	+0.008	+0.006	
5400.711	*Fe*	3	2	11	+0.006	+0.004	
5405.989	*Fe*	6	sh$_1$	11	+0.009	+0.007	
5410.000	*Cr*	4	4–5	11	+0.007	+0.004	
5420.56	*Mn*	1	2w$_2$	11	+0.005	+0.002	
5424.290	*Fe*	6	sh$_1$	11	+0.007	+0.004	
5429.911	*Fe*	6d?	6–7sh$_1$	11	+0.009	+0.006	
5432.753	*Mn*	1Nd?	2w$_2$	11	+0.007	+0.005	
5433.160	*Fe*	2	1–2	11	+0.008	+0.006	
5434.740	*Fe*	5	5–6	11	+0.010	+0.007	
5446.797	*Ti*	2	1–2w$_1$	11	+0.006	+0.004	
5447.130	*Fe*	6d?	sh$_1$	11	+0.010	+0.007	

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5455.671	*Fe?*	2	1w_2	10	+0.006	+0.004	
5455.834	*Fe*	4	4–5w_1	10	+0.008	+0.005	
5470.84	*Mn*	1	2w_2	10	+0.007	+0.004	
5477.123	*Ni*	5	4–5	9	+0.010	+0.007	
5483.566	*Co*	1d?	1–2w_2	10	+0.010	+0.007	
5497.735	*Fe*	5	5–6	9	+0.012	+0.009	
5501.683	*Fe*	5	5–6w_1	9	+0.010	+0.007	
5507.000	*Fe*	5	5–6w_1	9	+0.011	+0.008	
5512.741	*Ti*	2	w_1	7	+0.009	+0.006	
5514.753	*Ti*	2	2	7	+0.008	+0.005	
5528.641	*Mg*	8	sh_2	8	+0.008	+0.005	
5569.848	*Fe*	6	5sh_1	10	+0.011	+0.008	
5576.320	*Fe*	4	3	10	+0.011	+0.008	
5582.198	*Ca*	4	5	8	+0.007	+0.004	
5586.991	*Fe*	7	6sh_1	8	+0.010	+0.007	
5588.985	*Ca*	6	sh_1	8	+0.007	+0.005	
5590.343	*Ca*	3	3	8	+0.007	+0.004	
5594.691	*Ca*	4	3–4	7	+0.009	+0.006	
5594.884	*Fe*	1	0	7	+0.015	+0.012	
5598.711	*Ca*	4	4	5	+0.006	+0.003	
5601.505	*Ca*	3	3	5	+0.008	+0.005	
5615.877	*Fe*	6	5sh_1	5	+0.009	+0.006	
5682.869	*Na*	5	7w_1	6	+0.007	+0.004	
5684.710	*Si*	3	2w_1	6	+0.010	+0.008	
5688.436	*Na*	6	7w_1	6	+0.006	+0.003	
5690.646	*Si*	3	2w_1	6	+0.008	+0.005	
5701.323	*Si*	1N	w_1	6	+0.007	+0.004	
5708.622	*Si*	3N	2	6	+0.009	+0.006	
5709.775	*Ni*	5	4–5	6	+0.012	+0.009	
5727.271	*Ti–V*	2N	2–3w_1	4	+0.004	+0.001	
5772.364	*Si*	3	2–3w_1	6	+0.008	+0.005	
5798.077	—	3	2–3	5	+0.009	+0.006	
5853.902	*Ba?*	5	6w_1	7	+0.006	+0.003	
5857.976	*Ni*	3	2w_1	6	+0.011	+0.008	
5862.582	*Fe*	6	6	6	+0.009	+0.006	
5866.675	*Ti*	3	3–4w_2	6	+0.007	+0.004	
5890.186	*Na*	30	50sh_3	7	+0.001	−0.002	
5893.097	*Ni*	4d?	3–4	8	+0.012	+0.009	
5896.155	*Na*	20	40sh_3	8	+0.001	−0.002	
5934.881	*Fe*	5	5	6	+0.011	+0.008	
5948.765	*Si*	6	5–6	6	+0.010	+0.007	
5953.386	*Ti*	1	w_1	6	+0.006	+0.003	
5956.923	*Fe*	4	4–5	6	+0.010	+0.007	
5977.007	*Fe*	4	4	6	+0.010	+0.007	
6008.785	*Fe*	6	w_1	7	+0.011	+0.008	
6013.715	*Mn*	6	6–7w_2	7	+0.007	+0.004	
6016.861	*Mn*	6	w_2	7	+0.007	+0.004	
6020.401	*Fe*	4	3	7	+0.013	+0.010	
6022.016	*Mn*	6	w_2	7	+0.007	+0.004	
6024.281	*Fe*	7	7	7	+0.011	+0.008	
6042.315	*Fe*	3	w_1	7	+0.010	+0.007	Enhanced line of *Fe*
6065.709	*Fe*	7	7	5	+0.012	+0.009	
6079.227	*Fe*	2	1–2	5	+0.012	+0.009	Enhanced line of *Fe*

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6082.930	*Fe*	1	1	5	+0.010	+0.007	
6102.392	*Fe*	6	$5w_2$	4	+0.013	+0.010	
6102.937	*Ca*	9	10	5	+0.008	+0.005	
6122.434	*Ca*	10	12	5	+0.007	+0.004	
6136.829	*Fe*	8	7	5	+0.013	+0.010	
6141.938	*Fe, Ba*	7	9	5	+0.004	+0.001	
6149.458	*Fe*	2	1	5	+0.013	+0.010	Enhanced line of *Fe*
6151.834	*Fe*	4	4	5	+0.012	+0.009	
6154.438	*Na*	2	2–3	5	+0.011	+0.008	
6160.956	*Na*	3	4	7	+0.012	+0.008	
6162.390	*Ca*	15	sh_1	7	+0.008	+0.005	
6166.651	*Ca*	5	5	7	+0.009	+0.006	
6169.249	*Ca*	6	6	7	+0.010	+0.006	
6169.778	*Ca*	7	7	6	+0.009	+0.006	
6173.553	*Fe*	5	w_1	7	+0.014	+0.011	
6175.584	*Ni*	3	2–3	7	+0.011	+0.008	
6177.027	*Ni–*	5	4	7	+0.011	+0.007	
6191.393	*Ni*	6	6	7	+0.011	+0.008	
6191.779	*Fe*	9	$8w_2$	7	+0.014	+0.010	
6213.644	*Fe*	6	w_2	7	+0.014	+0.011	
6230.943	*V–Fe*	8	8	9	+0.011	+0.008	
6238.598	*Fe*	2	1	8	+0.012	+0.009	Enhanced line of *Fe*
6246.535	*Fe*	8	7–8	12	+0.014	+0.011	
6247.774	*Fe*	2	1	12	+0.014	+0.011	Enhanced line of *Fe*
6252.773	*Fe*	7	w_1	12	+0.013	+0.010	
6258.322	*Ti*	2	$2–3w_1$	12	+0.007	+0.004	
6258.927	*Ti*	3	$3–4w_1$	12	+0.008	+0.005	
6265.348	*Fe*	5	w_2	12	+0.013	+0.010	
6301.718	*Fe*	7	6	11	+0.012	+0.009	
6302.709	*Fe*	5	5	11	+0.012	+0.009	
6318.239	*Fe*	6	5–6	11	+0.014	+0.010	
6337.048	*Fe*	7	7	11	+0.012	+0.009	
6380.958	*Fe*	4	4	6	+0.008	+0.005	
6408.233	*Fe*	5	4	9	+0.011	+0.008	
6417.133	*Fe?*	1	0	9	+0.012	+0.009	Enhanced line of *Fe*
6420.169	*Fe*	4	3	9	+0.010	+0.007	
6431.066	*Fe*	5	$5w_1$	9	+0.012	+0.008	
6439.293	*Ca*	8	8	9	+0.006	+0.003	
6450.033	*Ca*	6	6	9	+0.006	+0.003	
6455.820	*Ca*	2	2	9	+0.008	+0.005	
6456.603	*Fe*	3	1	9	+0.013	+0.010	Enhanced line of *Fe*
6494.004	*Ca*	6	$5–6w_1$	9	+0.007	+0.003	
6495.213	*Fe*	8	6	9	+0.013	+0.009	
6497.128	*Fe*	4	5	9	+0.005	+0.002	
6499.168	*Fe*	1	1–2	9	+0.008	+0.005	
6499.880	*Ca*	4	$4w_1$	9	+0.008	+0.005	
6516.311	*Fe*	2	0	9	+0.013	+0.010	Enhanced line of *Fe*
6546.479	*Ti–Fe*	6	5	9	+0.011	+0.007	
6563.045	*H*	40	$60w_3sh_2$	8	+0.002	−0.002	Width of $H\alpha$ at limb =1.15 Ångströms
6569.460	*Fe*	5	4	9	+0.010	+0.007	
6573.030	*Ca?*	1	1–2	9	+0.008	+0.005	

show no appreciable displacement. The other lines of calcium, sodium, and magnesium show displacements, which, though varying considerably among themselves, are, as a rule, smaller than those for most of the other elements.

2. The displacements for titanium, vanadium, and scandium are considerably smaller than those for iron or nickel.

3. The lines of the elements of very high atomic weight, such as lanthanum and cerium, show very small displacements.

4. The lines of the cyanogen flutings are shifted by small but appreciable amounts.

5. One or two lines in the list are shifted unmistakably toward the violet. The most pronounced case of this sort is λ 4527.490 of titanium.

6. The lines which are considerably strengthened at the limb usually show small displacements.

7. The enhanced lines as a class show decidedly larger shifts than do the arc lines, especially in the more refrangible part of the spectrum. The enhanced lines of titanium are shifted less than those of iron, the latter giving the largest average displacements of any lines in the list.

It is hardly necessary to comment extensively on (1) and (2) in this list, except so far as to call attention to the fact that they point to a low-level cause for the displacements. The lines enumerated under (1) are known to rise to the highest level of any in the solar spectrum, and even the other lines due to these elements, as well as those of titanium, vanadium, and scandium, are known from chromospheric observations to lie at an appreciably higher average level than those of iron, for example. The cause producing the observed displacements accordingly must be inferred to be most effective at the lower levels.

The point referred to under (3), that the elements of very high atomic weight show small shifts, is of decided interest, especially in view of the fact that laboratory results seem to indicate that pressure-shifts increase in general with the atomic weight of the element. A very simple explanation, however, presents itself. The lines of these elements are greatly weakened at the limb, in some cases being almost obliterated. It is known that the vapor giving rise to these lines

lies in a thin layer close to the solar photosphere. At the sun's limb the light from this low-lying layer is probably considerably scattered in the course of the long path traversed through the overlying gases, as well as actually cut off in large part by the higher portions of the photosphere, which, seen in projection at the limb, act as a shield, shutting off the view of all below their own level. A similar explanation would account in a simple way for the disappearance of the wings from most of the heavy winged lines at the sun's limb. In such a case it is evident that if a part of the layer of gas producing, for example, a lanthanum line, is concealed from view, the path of the light from the remainder might be no longer, and, in fact, could be shorter, than at the center of the sun. For an equal path we should expect practically no displacement, and this is essentially what is found for the average of the lines of lanthanum and cerium which have been measured.

The displacements of the lines in the cyanogen fluting have been discussed previously. In addition it should be stated that some of the lines in the ultra-violet fluting are probably blended with the lines of elements which show marked displacements, and that this may account for the abnormally large values given by certain of the lines. This region is so extraordinarily rich in lines that even with very high dispersion cases of this kind are almost certain to occur. The same is probably true of the line λ 4207.566 ascribed by Rowland to *CN*. There can be little doubt that this line is a blend, its width being much too great for a single line of its intensity.

The greater number of negative displacements shown in the list are without doubt to be regarded as due simply to errors of measurement. The titanium line at λ 4527.490, however, is unquestionably an actual case of a negative displacement. Measures on six plates have given for this line

$$-0.005, \; -0.006, \; -0.007, \; -0.003, \; -0.003, \; -0.003 \text{ Ångström.}$$

In the arc spectrum it is a line of medium intensity, and, so far as I know, is abnormal in but one respect. Under the influence of a magnetic field it is separated into seven components, of which four are produced by vibrations in a plane perpendicular to the lines of force, and the other three by vibrations parallel to the lines of force. In

the spectrum of a spark under pressure its behavior is entirely normal, the displacement being toward the red and about equal numerically to the shifts of the other lines in its vicinity. At present there seems to be no adequate explanation for the behavior of this line. If magnetic effects influenced the spectrum at the center or the limb of the sun to any considerable extent, a reasonable conclusion would be that, owing to a difference of polarization, different components might be involved in the two regions, and so an apparent shift of the line might be introduced. Visual and photographic experiments with a Nicol prism and rhomb indicate, however, that if any such magnetic effects are present they are too minute to be detected with the dispersion employed.

The conclusion given under (6), that the lines most strengthened at the limb usually show small displacements, is based rather on the means of groups of lines than upon separate cases, since there are numerous individual exceptions to it. On the whole, however, the tendency seems to be well marked. Among iron lines especially noticeable cases are λ 4482.3 and λ 6497.128, which are greatly strengthened and show very small shifts. The lines λ 4232.887, λ 4258.477, λ 4291.630, λ 4461.618, and λ 4489.911 are all instances of iron lines which are decidedly strengthened and which show moderate shifts. The whole question is greatly complicated by the general widening of the lines and the difficulty of estimating actual increases of intensity, as well as by the fact that we have little knowledge of the displacements of most of these lines under pressure in the laboratory. It seems probable from comparisons of the strengthened and the weakened lines at the limb with those in sun-spots, that the principal changes in intensity (especially for the strengthened lines) are to be explained on the basis of temperature. Since the lowest temperature is probably to be found in the higher portions of the sun's atmosphere, the lines showing marked strengthening are to be regarded as high-level lines. For such lines the increase in the length of path in the upper layers would be of great relative importance, and might result in an increase of intensity. For the same reason we should expect their displacements to be small. The behavior of known high-level lines, such as $H\alpha$, the D lines of sodium, and the *b* lines of magnesium, all of which lose their wings at the

limb and are decidedly strengthened, lends considerable weight to this hypothesis.

Reference should also be made at this point to the apparent tendency on the part of the strong winged lines of iron to give smaller displacements than would be expected. This effect is by no means proven, but there is sufficient evidence to furnish a considerable presumption in its favor. If present it is probably due to the fact that, as stated in the discussion of (3), a portion of the iron vapor, which lies lowest in the solar atmosphere and which produces the wings on these lines at the center of the sun, is concealed from view at the limb. This gas is under the greatest pressure and its obscuration tends to reduce the total amount of displacement at the limb.

The results found for the enhanced lines form perhaps the single most important product of this investigation. The fact that these lines as a class give the largest displacements of any in the spectrum has proved the more unexpected as it is directly opposed to the conclusion of Halm,[1] derived through measures of the enhanced line of iron at λ 6516.311. The result of Halm's measures on this line was a shift of -0.002 Ångström, an amount which he considered practically negligible. My own observations, based on nine measures, give $+0.013$ Ångström, one of the largest displacements found in this part of the spectrum. I am quite unable to account for this discrepancy. My results for the other enhanced lines in this region, however, confirm the larger value. Thus we have:

λ	Δ
6238.598	+0.012
6247.774	+0.014
6456.603	+0.013
6417.133	+0.012

A total of 85 enhanced lines is included in the results of these measures. Of these, 45 are due to titanium and 27 to iron, with the remainder divided among chromium, vanadium, and other elements. In each case the mean displacement for a group of these lines averages higher than that for an equal number of arc lines of the same element. Toward the less refrangible end of the spectrum, however, the difference becomes less marked, until in the red, in the

[1] *Astronomische Nachrichten*, **173**, 273, 1907.

case of iron at least, the values become essentially equal. More complete numerical data will be given in connection with the discussion of the variation of the displacements with wave-length, but a brief analysis of the region λ 4400–λ 4600, which is very rich in enhanced lines, will perhaps be of interest at this point. For this region we find as the average displacements:

12 arc lines of *Ti*	+0.004
11 enhanced lines of *Ti*	+0.007
12 arc lines of *Fe*	+0.007
9 enhanced lines of *Fe*	+0.010

It is noteworthy that the enhanced lines of titanium differ from the enhanced lines of iron by just the same amount as the arc lines of the two elements.

There appears to be a general tendency for the displacements of the enhanced lines to increase with the degree of enhancement in the spark spectrum. This effect is hardly more than roughly indicated, but it probably deserves a word of comment. It seems to hold especially for the enhanced lines which either are not seen at all, or appear as mere traces in the arc spectrum. Thus, if we take Lockyer's list of enhanced lines in the iron spectrum between λ 3846 and λ 5316, we find that ten lines out of eighteen are given as zero or fainter in the arc spectrum. The mean displacement for these ten lines is +0.010 Ångström as against +0.008 Ångström for the other eight lines. An especially noteworthy case is λ 4385.548, which is given by Lockyer as a "trace" in the arc spectrum. This line shows a shift of +0.013 Ångström, the largest value obtained from any line to the violet of λ 5500. The titanium lines show a very similar behavior, except that the number of enhanced lines which are very faint in the arc spectrum is relatively considerably smaller than for iron. The whole question is a most interesting one, but more evidence is needed, both on the solar and on the laboratory side, to make adequate discussion possible. Reference should, however, be made to the fact that there seems to be a well-defined relationship between the amount of enhancement of these lines in the spark spectrum and the amount of their weakening in the spectrum of sun-spots.[1] There can be little doubt that both of these effects

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 40; *Astrophysical Journal*, **30**, 86, 1909.

are intimately connected with the origin of these lines in the solar spectrum.

The level occupied by the enhanced lines in the solar atmosphere has been a subject of considerable discussion. The fact that they appear in the "flash" and chromospheric spectrum with an intensity out of proportion to the intensity of the dark lines which correspond to them in the general solar spectrum, is at present hardly questioned seriously. Quite a different interpretation of this result is given by different observers, however. Thus Lockyer and Fowler regard the enhanced lines as chiefly restricted to the higher levels of the chromosphere, while Evershed and some others conclude that there is no essential difference in their relative intensities throughout the entire depth of the chromospheric layer. A most interesting theory is advanced by Evershed to account for the differences of relative intensity of the enhanced lines in the dark-line solar spectrum and in the "flash" spectrum.[1] In accordance with his view, the enhanced lines find their origin chiefly in the jets of intensely hot gas which are found ascending in a radial direction all over the surface of the sun. These regions would correspond more closely to the conditions present in the electric spark, while the cooler descending gases would better represent those present in the arc. At the sun's limb, accordingly, the light from the radiations characteristic of the very hot gases (the enhanced lines) would traverse the long path through the other cooler gases with little diminution of intensity. The cooler gases would, however, tend to neutralize that portion of the more intense spectrum of the hot gases which is common to the temperatures of both. Of the spectrum at the center of the sun Evershed writes:

> The relatively cool gases would obviously determine the character of the absorption spectrum of the disk, and the only effect of the hotter eruptions, supposing them to be too small to be individually distinguishable in the spectroscope, would be to produce a faint emission line of about the same intensity as the background of continuous spectrum, and tending to diminish the intensity and width of all the dark lines, particularly the enhanced spark lines.

The latter part of this statement is not wholly clear to the writer. It would seem that if the radiations characteristic of the enhanced lines (for the moment limiting these to such as do not appear at all

[1] J. Evershed, "Solar Eclipse of 1900, May 28.—General Discussion of Spectroscopic Results," *Philosophical Transactions*, A, **201**, 457.

in the arc spectrum) can be emitted only by the hotter ascending gases, the corresponding absorption lines found on the disk of the sun can be produced only by these gases as well. In other words, we should ascribe the presence of the dark enhanced lines of the solar spectrum almost entirely to these ascending jets of very hot gas.

An interesting point of evidence bearing on this question is furnished by the observations of Fox on the spectrum of one of the dark interstices or "pores" between the granulations on the surface of the sun.[1] He found a slight but unmistakable difference in the character of the spectrum in the direction of that observed in sun-spots. That is, the spectrum of the pore indicates a region of cooler temperature than does the general solar spectrum. Since the latter is made up of the mingled light from many pores and granulations, it is clear that the spectrum of the granulations must be characteristic of regions of higher temperature in order to give the average found in the ordinary solar spectrum. This is what Evershed's theory requires.

The application of this discussion to the results found from measurements of the displacements of the enhanced lines is of great interest. If the enhanced lines are due almost exclusively to the ascending streams of intensely hot gas (the granulations), while the other dark lines in the spectrum are due both to the pores and the granulations, it is clear that the enhanced lines, if compared with the corresponding lines in the spectrum of the spark (neglecting pressure-shifts), would show a slight displacement to the violet, while the other lines would show either no displacement, or a very minute displacement toward the red, owing to the preponderance of the effect of the pores. Even for the enhanced lines the shift would be difficult of measurement in any direct manner. Through measurement of the center and the limb, however, double the amount is obtained, and this in a purely differential way. Accordingly, on this basis, a simple explanation is afforded of the larger displacements shown by the enhanced lines. It is due to the fact that these lines are affected relatively more by the ascending currents at the center of the sun than are the other lines in the spectrum. Furthermore, it is evident that such of the enhanced lines as appear in the

[1] From a paper read at the 1909 meeting of the American Astronomical and Astrophysical Society, but, so far as I know, not yet published.

arc spectrum can probably be produced to some extent by the pores. For these lines, accordingly, we should expect the displacements to be less, that is, for the lines as a whole the displacements will be the greater, the greater the amount of enhancement. That such is apparently the case, we have already seen. In addition it should be noted that the fact that the difference of displacement between the enhanced and the arc lines is the same for iron and titanium indicates that the cause producing the larger displacements is of such a character as to affect different elements equally. This would argue for an external cause rather than for one inherent in the nature of the enhanced lines themselves.

The amount of the motion in the solar granulations which would account for the difference between the enhanced lines and the arc lines may be found readily in the same way as in the earlier case of the cyanogen lines. The average difference between the displacements of the enhanced and the arc lines of iron and titanium is about 0.003 Ångström, and the few scattered lines of other elements give approximately the same value. An upward motion in the solar granulations of about 0.12 km a second, an amount sufficient to produce a displacement of 0.0015 Ångström, would account for the results found. This is, of course, a mean value from enhanced lines of all sorts, including such as appear to some extent in the arc spectrum. It is probable that the granulations move somewhat faster than this, since the lines which are most enhanced show differences of 0.004 or 0.005 Ångström from the arc values.

Another possible explanation of the larger displacements given by the enhanced lines must not, however, be overlooked. This is the possibility that the enhanced lines may show larger shifts under pressure in the laboratory. Practically all of the investigations up to this time on the effect of pressure have been carried out with the use of the electric arc, and so these lines have not been employed. An investigation of the spark under pressure was begun by Mr. Gale in the Pasadena Laboratory in March 1909, but unfortunately was interrupted by an accident to the observer. It is hoped that it may be continued during the coming year.

We now may pass to the consideration of pressure as a means of accounting for the displacements found at the sun's limb. A

brief summary of the points bearing on this question will be of value.

1. The displacements are largest for the elements which lie at the lowest level in the sun's atmosphere. This is exclusive of such elements as lanthanum and cerium, the behavior of which has already been discussed in full.

2. The displacements increase with the wave-length of the lines observed.

3. The lines of the cyanogen flutings are but very slightly shifted, and these shifts are satisfactorily accounted for by small motions in the line of sight at the center of the sun.

4. Direct comparisons of the two limbs and the center of the sun with the spectrum from an electric arc have shown that the displacements cannot be due to currents in the reversing layer moving parallel to the surface of the sun.

5. The lines measured, with the exception of certain very high-level lines, such as those of hydrogen, calcium, sodium, and magnesium, are widened on the red edge, the violet edge retaining its normal position. This result is in agreement with that found by Buisson and Fabry.

These different considerations are all strongly in favor of pressure as the agent effective in producing the displacements observed. A direct comparison with laboratory results, however, is made most difficult by the question of the level of the various lines involved. This is shown clearly by the following simple calculation. Let us assume four layers of gas each 500 km thick, one above the other, over the surface of the sun. If the radius of the sun is taken as 740,000 km the length of path traversed by the light at the sun's limb would be

For the lowest layer	27,100 km
For the second layer	11,300
For the third layer	8,700
For the fourth layer	7,300

In practice, of course, no photographs have been taken exactly at the sun's limb on account of the disturbing effect of the chromospheric spectrum, but at a small distance inside. Accordingly these quantities would be greatly modified. If we assume as an average for the plates a distance inside the limb of 0.2 mm, which corresponds to about 1760 km on the sun's radius, we find

For the lowest layer	6,800 km
For the second layer	6,080
For the third layer	5,560
For the fourth layer	5,150

Accordingly, for a gas which rises to a height of 1000 km above the sun's surface the ratio of the lengths of path in the lower and the upper layers is 1.12 to 1, while it is 1 to 1 at the center of the sun. Since the density of the gas increases very rapidly toward the surface of the sun, the magnitude of this effect would be increased by dividing the stratum of gas into thinner layers and considering their action separately. Moreover, in the case of elements which rise to a considerable height in the sun's atmosphere, the density of the gas in the lower strata is much less than in the case of low-lying elements. This is well illustrated by the fact that the lines of titanium show almost no wings, even when of equal intensity to some of the strongly winged lines of iron. Accordingly, for such an element the effect of an increase in the length of path in the lower strata of the gas will be much less than for gases confined to a lower level. Hence we should expect to find the lines of iron showing comparatively large displacements, while those of titanium would show considerably smaller values.

Since the matter of level appears to be the most significant factor in determining the amount of displacement for any given line, and since the different lines, even of the same element, in the solar spectrum, show wide differences of level, it is clear that any agreement with laboratory pressure-shifts can at best be only approximate. Some comparison of the sort should, however, be made.

In the case of iron, if we take the values given by Humphreys for the lines in the list,[1] and divide them into two sets according as the shift for a pressure of 42 atmospheres is less or greater than 0.1 Ångström, we obtain the following comparisons:

Number of Lines	Average Pressure-Shift	Displacement at Limb
25	+0.065	+0.007
15	+0.197	+0.009

While the displacements at the limb are larger for the lines showing

[1] *Jahrbuch der Radioaktivität und Elektronik,* **5**, 324, 1908.

the larger pressure-shifts, the ratios are widely different. A considerable part of this is due, however, to three lines in the list near λ 4900, which show enormous displacements under pressure. The omission of these lines would reduce the average pressure-shift to +0.148 Ångström, while the displacement at the limb would remain the same. It seems probable that in the sun these three lines are of comparatively high level. The line λ 4494.738 agrees very well with the laboratory results. At a pressure of 42 atmospheres it shows the large displacement of +0.200 Ångström. The displacement at the limb is +0.010 Ångström, which is also very large for this region of the spectrum. On the other hand the line λ 4447.892, which is displaced +0.180 Ångström in the laboratory, shows but +0.005 Ångström at the limb.

In the case of titanium the results are very similar, but the laboratory material is much more limited. A comparison with the values of Humphreys gives the following results:

Number of Lines	Average Pressure-Shift	Displacement at Limb
6	+0.048	+0.003
6	+0.120	+0.005

The material available for the other elements is so fragmentary as to make comparisons of little value. Attention should, however, be called to the group of nickel lines at about λ 4650. These show very large displacements under pressure in the laboratory. At the limb they give an average displacement of +0.009, which is also exceptionally large for this region of the spectrum.

In conclusion it may be said that the comparison of the laboratory with the solar displacements is on the whole in favor of the view that pressure produces the observed shifts. Though the agreement is by no means complete, the average values are uniformly in the same direction. Moreover, the discordances are almost always in the direction of too small values for the solar displacements. This is precisely what would be expected. In the laboratory the entire mass of vapor producing the spectrum lines is under the same pressure. In the sun, on the other hand, there is a pressure gradually increasing downward throughout the strata whose absorption produces the dark

lines. The result is that the lines are widened toward the red, the violet edges retaining their normal positions, and the measures made on the centers of the line can give only an average value.

In a recent discussion of the application of anomalous dispersion to solar phenomena,[1] Julius has ascribed the displacements found at the sun's limb to this cause. According to his point of view the photospheric light is anomalously refracted in the vicinity of the absorption lines produced by the metallic vapors, and, since in general the density-gradient decreases outward, the widening will be upon the red side of the lines producing the observed displacements. The fact that the sodium lines D_1 and D_2 are not displaced, although they show the largest amount of anomalous dispersion of any which have been investigated for this effect, is rather strongly opposed to this view. The same is true of H, K, and λ 4227 of calcium, all of which show strong anomalous dispersion but are not displaced at the limb. Since these lines, however, might be considered as somewhat exceptional, I have made a comparison with a large number of lines investigated by Geisler.[2] The results are summarized below.

Element	Anomalous Dispersion				Displacement at Limb
	Strong	Moderate	Weak	Very Weak	
Aluminium	..	2	..	..	+0.002 Å
Barium	2	..	..	..	+0.011
	..	1	..	..	+0.004
	..	..	..	1	+0.006
Calcium	3	..	..	..	+0.001
	..	..	4	..	+0.007
	..	..	..	18	+0.007
Chromium	4	..	..	..	+0.006
	..	..	3	..	+0.008
	..	..	..	2	+0.006
Cobalt	..	..	..	1	+0.006
Iron	..	..	2	..	+0.005
	..	..	..	7	+0.007
Magnesium	..	..	3	..	0.000
	..	..	..	2	+0.001
Manganese	1	..	..	..	+0.007
Sodium	2	..	..	..	+0.001
Strontium	1	..	..	..	+0.001
Zinc	3	..	..	..	+0.007

[1] To be published in *Memorie della Società degli Spettroscopisti Italiani.*

[2] *Zeitschrift für wissenschaftliche Photographie,* **7**, 89, 1909.

There seems to be no clear relationship between these results. The values for calcium, sodium, and strontium would appear to indicate that lines showing the greatest anomalous dispersion give the smallest displacements. The results for manganese and barium, however, appear to contradict this. Without much more positive evidence it is difficult to see how any relationship between anomalous dispersion and these results can be considered as established.

	Calcium			Nickel		
λ	Δ	Δ′	No. Lines	Δ	Δ′	No. Lines
3700–4200	....	....	..	+0.0050	+0.0030	3
4200–4700	+0.0056	+0.0034	11	0.0077	0.0052	4
4700–5200	0.0055	0.0035	2	0.0075	0.0048	8
5200–5700	0.0067	0.0042	9	0.0100	0.0070	1
5700–6200	0.0085	0.0053	6	+0.0113	+0.0082	6
>6200	+0.0072	+0.0040	6	....	....	..
	Iron			**Enhanced Iron**		
λ	Δ	Δ′	No. Lines	Δ	Δ′	No. Lines
3700–4200	+0.0060	+0.0040	18	+0.0070	+0.0050	4
4200–4700	0.0065	0.0044	28	0.0104	0.0079	11
4700–5200	0.0083	0.0058	24	0.0090	0.0067	3
5200–5700	0.0095	0.0067	21	0.0120	0.0090	1
5700–6200	0.0116	0.0086	14	0.0117	0.0087	3
>6200	+0.0116	+0.0084	13	+0.0128	+0.0098	5
	Titanium			**Enhanced Titanium**		
λ	Δ	Δ′	No. Lines	Δ	Δ′	No. Lines
3700–4200	+0.0037	+0.0016	9	+0.0051	+0.0031	13
4200–4700	0.0049	0.0025	17	0.0070	0.0048	22
4700–5200	0.0051	0.0027	7	0.0068	0.0043	4
5200–5700	0.0075	0.0047	4	+0.0097	+0.0070	3
5700–6200	0.0065	0.0035	2	....	....	..
>6200	+0.0075	+0.0045	2	....	....	..

One of the most important questions relating to the displacements at the sun's limb is that of their variation with wave-length. The range of spectrum covered by the photographs is so great that an effect of this kind should be very marked. Moreover, it is made of especial interest by the fact that the proportionality between pressure displacements and wave-length cannot yet be considered as fully established for laboratory results. Thus in 1908 Humphreys writes:[1]

[1] *Jahrbuch der Radioaktivität und Elektronik*, **5**, 324, 1908.

Im allgemeinen scheint die Druckverschiebung von Spektrallinien mit der Wellenlänge zuzunehmen; aber wahrscheinlich gilt dies nur von den Linien derselben Serie. Jedenfalls ist es nicht zutreffend in Falle von Eisen, Nickel und anderen Elementen, deren Linien zu vielen Serien oder zu keiner zu gehören scheinen.

A simple inspection of the tables shows that the displacements increase toward the red end of the spectrum. In order to furnish a numerical comparison, however, I have collected the results for the principal elements in the following table, taking the means for the lines included within each 500 Ångström units of spectrum. Both Δ and Δ' are given.

Except in the case of iron the number of lines in some of the 500 Ångström intervals is so small, especially toward longer wave-lengths, as to make the influence of individual lines larger than it should be. Better results will probably be obtained by taking means over 1000 Ångströms. If Δ alone is considered we obtain the following values. The figures in parentheses after the displacements indicate the number of lines.

	λ 3700 – λ 4700	λ 4700 – λ 5700	> λ 5700
Ca	+0.0056 (11)	+0.0065 (11)	+0.0078 (12)
Fe	0.0063 (46)	0.0089 (45)	0.0116 (27)
Enh. *Fe*	0.0095 (15)	0.0098 (4)	0.0124 (8)
Ni	0.0065 (7)	0.0078 (9)	0.0113 (6)
Ti	0.0045 (26)	0.0060 (11)	+0.0070 (4)
Enh. *Ti*	+0.0063 (35)	+0.0080 (7)	......

An interesting difference is shown by the elements in this table. The displacements for calcium and titanium, for the latter element both for the arc and the enhanced lines, vary almost exactly in direct proportion to the wave-length. In fact the largest deviation from this relationship for these three sets of lines is 0.0003 Ångström. For the enhanced lines of iron the results are doubtful, but an approximately linear relationship seems to hold. For nickel, however, and the arc lines of iron, the displacements increase more rapidly than in direct proportion to wave-length. Thus for iron, where the direct proportion would require a ratio for the three values of 1:1.24:1.48, the ratio actually found is 1:1.41:1.84. Since the values for iron are of very high weight on account of the large number of lines employed, this result is, I think, to be regarded as genuine.

A most simple explanation of this difference of behavior is found in the scattering of light in the solar atmosphere. I have already referred to the great difference in the relative intensity of the spectrum of the center and the limb of the sun in different parts of the spectrum, the ratio of about 1 to 5 in the red increasing to about 1 to 15 in the ultra-violet. There can be little doubt that this difference is due to the relatively greater scattering of the ultra-violet light from the lower strata of the solar atmosphere in the long path traversed at the sun's limb. If such is the case we should expect the light from the gases of elements which are confined to the lower strata to be relatively more weakened than that from gases which extend throughout a considerable range of level. Moreover, since the vapors of iron and nickel lie at a considerably lower level than those of calcium and titanium, the contribution of the lowest strata to the formation of the absorption lines is relatively greater in their case. As these strata are under the greatest pressure this relative weakening of the light in the ultra-violet will show itself by reduced displacements in this part of the spectrum. Toward longer wave-lengths, on the other hand, the light from the lower strata will pass more freely, and displacements will increase rapidly. In the case of titanium and calcium the effect of these lower strata is relatively much less, and the influence of the increased scattering upon the displacements comparatively small.

There is but one other matter in the discussion of these results to which I wish to call attention. A considerable number of lines are included in this list, particularly in the less refrangible part of the spectrum, which are found as doublets, or in some cases triplets, in the spectrum of sun-spots. The range of displacement for these lines is considerable. Thus the *Fe* line at λ 6499.168 has a displacement of +0.008 Ångström, while another *Fe* line at λ 6213.644 has +0.014 Ångström. Both of these lines are doublets in the spot spectrum and show approximately the same separation. If we assume, as seems altogether probable from this investigation, that difference of displacement in general indicates difference of level, we must conclude that in sun-spots the distribution of the gases is very different from that in the reversing layer, or that the magnetic field extends with practically uniform strength throughout the range of level indicated by these lines.

I wish to express my appreciation to several members of the Computing Division, particularly Miss Lasby, Miss Waterman, and Miss Wickham, for assistance in the progress of this research. A large part of the measures of the plates included in the list are due to Miss Lasby.

MOUNT WILSON SOLAR OBSERVATORY
November 1909

INTENSITY RELATIONS IN THE HYDROGEN SPECTRUM

By P. G. NUTTING AND ORIN TUGMAN

The various lines of the hydrogen spectrum are known to vary in relative intensity as the intensity of excitation and gas density are varied. We have undertaken a quantitative study of these effects by comparing the intensities of α, β, and γ and certain parts of the primary spectrum when produced under varied conditions, with their intensities under fixed standard conditions.

The gist of the method was the use of two similar tubes, one of which was held constant as a reference standard while conditions in the other were varied. Both tubes were operated with small 5000- or 10,000-volt transformers, the current in each being controlled by variable resistances in the 120-volt side. A polarization spectrophotometer was employed throughout. The current through each tube passed through an alternating current precision milliammeter in all cases except when a condenser was used.

The tubes were connected together and to the pump, manometer, and hydrogen supply by all glass connections, so arranged that either or both tubes could be quickly refilled with pure dry hydrogen. Contamination with mercury was carefully guarded against. The tubes were always reduced to a non-conducting vacuum before refilling. A special form of oil manometer, previously described,[1] gave pressures down to 0.2 mm with sufficient accuracy without the use of a McLeod gauge. Gauge and pump oil and cock-grease (previously vacuum boiled) gave no evidence of contamination in the spectral tubes after the first few hours' exposure to a vacuum. The hydrogen employed was prepared electrolytically from alkaline solution and kept over phosphorus pentoxide until used.

After some preliminary work on the effects of temperature, age of tube, impurities, etc., we adopted an open circuit programme, the current passing through the tubes only when a double key was pressed. Thus the tubes remained at or near room temperature and were spared

[1] *Bulletin of the Bureau of Standards*, **4**, 514, 1907.

unnecessary use. The greatest difficulty in working with hydrogen is the rapid deterioration of the walls of the tube under the action of the discharge. This necessitated replacing the tubes or their capillary portions after about an hour's use. Our results were obtained chiefly with large tubes having capillaries 2.6 mm in diameter and 7 cm long, viewed side-on at the middle. For these tubes 1 mm pressure and 15 milliamperes current was taken as the normal. Later, through the remarkable skill of Mr. Sperling, we were supplied with an end-on tube whose capillary portion was of porcelain. This tube carried as high as 500 m.a. and showed but slight deterioration after a week's service.

Readings were taken at six different wave-lengths, three in the secondary, α 656, β 486, and γ 434, and three in the primary referred to as a, b, and c, the approximate wave-lengths of which are 611, 545, and 460 $\mu\mu$. Both ocular and collimator slits were open about 6 $\mu\mu$.

VARIATION OF LINE-INTENSITY WITH CURRENT

The data taken with heavy currents, using the tube with porcelain capillary, are given below. The range of current was from 20 to 440 milliamperes. The porcelain capillary was 3.0 mm in diameter and 30 mm long, and was viewed end-on. All values for light-

Current Milliamperes	Line-Intensity ÷ Intensity at $i=20$			
	S_α	S_β	S_γ	P_{abc}
20	1.0	1.0	1.0	1.0
40 (4 sets)	2.6	2.2	2.0	1.7
50	3.9	2.6	2.9	2.3
75	5.4	3.9	2.7	3.3
120 (3)	14.2	10.2	5.5	4.4
200 (2)	20.5	17.0	6.5	7.1
250 (5)	29.2	18.1	10.7	8.2
300 (3)	48.8	18.2	16.3	8.9
370	57.0	26.5	14.0	11.5
380 (2)	59.5	24.0	12.0	10.7
400 (2)	....	....	....	13.0
440 (2)	66.0	26.5	....	11.1

intensity are in terms of the intensity at 20 m.a. A zero reading ($i=20$) was taken just before and just after the reading for each higher current and if the zero showed any change the reading was rejected. Both tubes were filled with fresh gas at 1 mm pressure for

each set of observations. The primary spectrum showed no selective (wave-length) effect as great as 2 per cent. even at the highest currents, so the three readings for the three spectral regions are grouped together in the column headed *Pabc*.

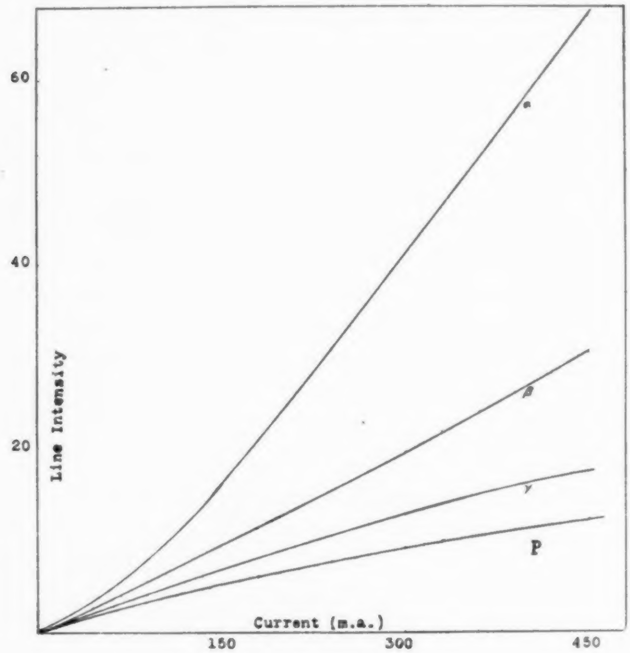


FIG. 1

A least-square reduction for the intensity P of the primary spectrum gives

$$P=P_{20}\left[1.042\frac{i}{20}-.0432\left(\frac{i}{20}\right)^2+.00098\left(\frac{i}{20}\right)^3\right],$$

while for the three lines of the secondary spectrum

$$S_\alpha=P^{1.67}\ ;\quad S_\beta=P^{1.35}\ ;\quad S_\gamma=P^{1.14}$$

for all currents. Hence,

$$S_\alpha^{0.599}=S_\beta^{0.729}=S_\gamma^{0.876}=P,$$

all referred to intensity at 20 m.a. as a unit.

In the relation

$$S=P^m,$$

m as a function of λ may be closely represented by

$$m=681\left(\frac{1}{251}-\frac{1}{\lambda}\right).$$

The uncertainty in the computed values of m is about 2 per cent. The deviations of m from the mean indicate that it is entirely independent of the current.

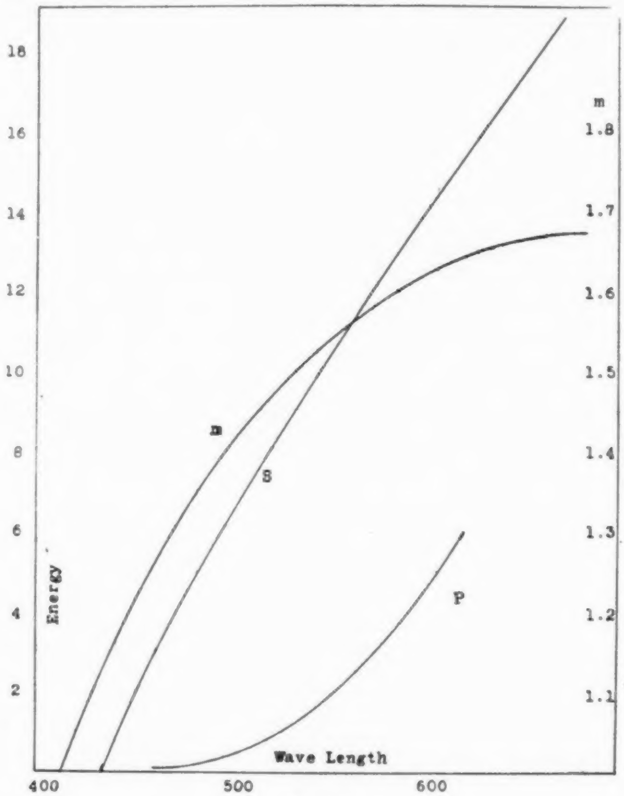


FIG. 2

These data are shown graphically in Figs. 1 and 2. The computed curves for α, β, and γ fit the data as well as any that could be drawn. The curve for m indicates that the fifth secondary line (λ 397) would vary at the same rate ($m=1$) as the primary spectrum, while lines farther out toward the head of the series would increase less rapidly than the primary with increase in current.

The most probable values of the spectral intensity taken from the adjusted curves are:

i	P	α	β	γ
20	1.00	1.00	1.00	1.00
50	2.1	3.45	2.72	2.33
100	3.8	9.3	6.1	4.6
150	5.4	16.7	9.7	6.8
200	6.8	24.5	13.3	8.9
250	8.2	33.5	17.1	11.0
300	9.4	42.0	20.5	12.9
350	10.4	49.8	23.5	14.4
400	11.5	59.1	27.0	16.2
450	12.3	66.1	29.5	17.4

At half the normal current $i=10$, taking $P=0.60$, the intensities in the secondary would have been $\alpha=0.43$, $\beta=0.50$, $\gamma=0.56$, had these lines followed the same law as at high currents. The greatest observed differences between α and γ were only about 0.05 and varied in sign, so that we must conclude that there is no selective effect at these current-densities.

Finally the energy emission at standard current (20 m.a.) was obtained by comparison with a carbon filament glow-lamp whose energy-curve at a given voltage had been determined by Dr. Coblentz. The uncertainty in the data given is perhaps 5 per cent.

Line	λ	Lamp E	Hyd. E
α..................	656	197	184 ($E_\gamma=1$)
β..................	486	24	58 ($E_\gamma=1$)
γ..................	434	7.0	1
a..................	611	130	59.7 ($E_c=1$)
b..................	515	38	8.3 ($E_c=1$)
c..................	460	14	1.0

Our data for small current-density was obtained with large glass tubes with capillary portions 2.6 mm in diameter and 7 cm long, of good quality, medium thickness, ordinary tubing. This was viewed from the side of the middle where it was reddest. The ends of the capillary are much whiter than the middle, indicating a larger proportion of primary spectrum. This end effect and the end-on effect were investigated separately. Readings are relative to those for

15 m.a. current. The data below were taken with six different tubes, either new or provided with fresh capillary, all of the same bore filled with gas at 1 mm pressure. Readings were taken at all six wavelengths in each case. As neither primary nor secondary spectrum showed any selective effect, the results for each spectrum are combined.

Current.........	2	3	5	7	9	12	15
Primary.........	0.163	.241	.34	.49	.65	.81	1.0
Secondary.......	0.043	.094	.17	.29	.42	.65	1.0

Writing as before $S = P^m$, $m = 1.73 \pm .02$, independent of the current as with large currents.

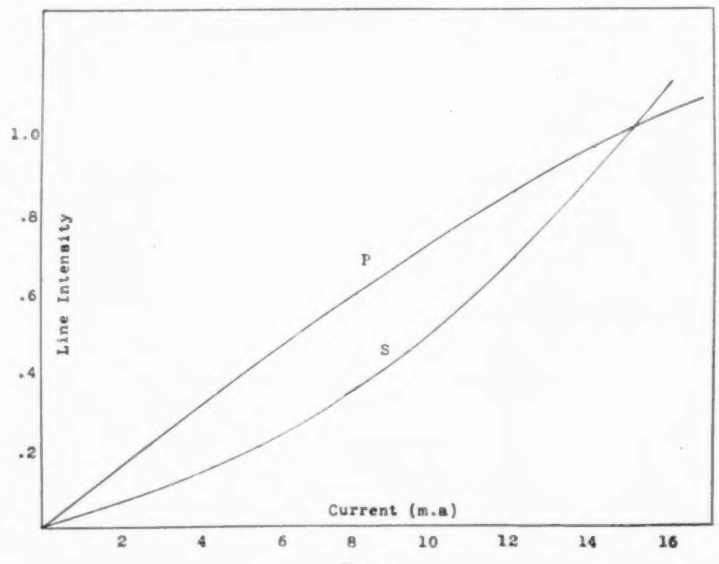


FIG. 3

This lack of selective effect at low current was at first attributed to lack of saturation in the thin column viewed from the side, but careful determinations at 10 m.a. with the end-on porcelain capillary tube showed that there was no selective effect in that case either. The nature of the secondary radiation must then change in the neighborhood of the current 20 m.a. and a little further study of the con-

duction of the gas and the theory of its radiation showed this to be plausible.

The potential-gradient in the 2.6 mm capillary was determined by cutting out about 10 cm of the capillary. This determination was made but twice, but results were in good agreement.

VOLTS PER CM IN *H*

M.A.	Pressure (mm)				
i	0.5	1.0	2.0	3.0	8.0
2	44.5	60.2	97.0	125	191
5	37.8	56.1	90.4	107	150
9	33.7	52.1	81.1	93	128
12	34.2	50.5	74.6	84	122
15	35.8	49.5	67.4	78	120

It may be noted that at 1 mm pressure there is a minimum gradient near 15 or 20 m.a., so that above and below this point different conditions of ionization obtain.

GAS-DENSITY AND OTHER EFFECTS

The effect of pressure on line-intensity at constant current was studied with glass tubes similar to those last described. From several hundred observations the following mean values were adopted. No selective effect was apparent in either primary or secondary, but these differ considerably from each other. All values are in terms of those at 1 mm pressure as unity.

Pressure	Secondary	Primary
0.25 mm	0.55	...
0.50	.78	0.80
0.75	.97	.97
1.00	1.00	1.00
1.5	.90	.92
2.0	.78	.85
3	.60	.72
4	.47	.61
5	.38	.53
6	.32	.48
7	.28	.44
8	.25	.41
10	.20	.38

The current was 15 m.a. (tubes in series) and the reference tube

filled at 1 mm pressure in each case. These results are shown graphically in Fig. 4.

With both tubes filled with hydrogen at 0.3, 0.5, 2, and 8 mm pressure and a current of 15 m.a. through the reference tube, readings were taken with variable current through the observation tube. These sets of readings differed very little from those taken at 1 mm pressure.

Temperature of wall.—When the capillary part of a tube was heated with a flame to about 200°, α fell off 20 to 30 per cent., while

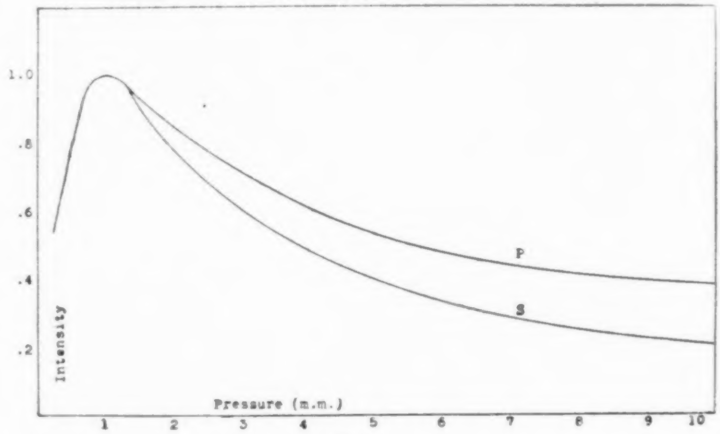


FIG. 4

β and γ and the whole of the primary were not affected by as much as 3 per cent. The tube recovers as it cools and the effect was repeated on several tubes. Since the current itself warms the tube 20° to 100°, very erroneous results may be obtained unless the tubes are maintained at constant temperatures.

Effect of use.—A tube of hydrogen after half an hour of continuous operation shows a marked decrease in intensity of all lines of both spectra. After an hour's run, a purple tinge may be detected in the capillary, and if this be cut out of the tube and viewed end-on, a layer of glass less than 0.2 mm thick, next to the inner wall, will be seen to be highly colored. This coloring is not affected by moderate heating but is completely removed by heating to the softening point of the glass; the effect increases steadily with continued use. Refilling

a tube with fresh gas at the same pressure produces no measurable effect on spectral intensity.

This effect on the inner wall might be due either to negative electron bombardment or to ionization by the extreme ultra-violet waves in which the hydrogen spectrum is so rich. We are inclined to the latter view. The effect is greater for hydrogen than any other gas. A helium tube has been run a hundred hours without appreciable deterioration at a current that would have produced a 10 per cent. change in a hydrogen tube in half an hour.

Oxygen with hydrogen.—Both reference tube and working tube were filled with hydrogen at 2 mm pressure, then zero readings were taken, the reference tube closed off, and an additional 2 mm of oxygen admitted to the working tube. Then with tubes in series (15 m.a. through both) it was found that the oxygen had cut down α, β, and γ about 30 per cent. each, and a, b, and c considerably more than that amount, and a more than c so that the red primary barely showed. The net effect of the oxygen then is to make the secondary spectrum much more prominent. It is easy to see why this spectrum has so often been attributed to water-vapor. This is a rich field for further study; we have touched upon it only to guard against possible error.

In the *cathode glow* and *striations* the relation of primary to secondary varies from that in the ordinary anode column. The primary is relatively brighter (50 per cent.) in the brighter parts of the striations where recombination is supposed to be particularly active. In an ordinary tube with disk electrodes and plenty of room for the cathode glow, the secondary is slightly more prominent in that glow than in the capillary; but in other tubes with cylindrical electrodes set close to the walls, the cathode's glow is nearly white and strongly favors the primary.

At *atmospheric pressure* a zinc spark (2 mm) in hydrogen gave hydrogen spectra not very different nor in different proportion from those in the comparison tube. The increased width of the lines, however, made a more exact comparison difficult.

A ube with *fine capillary* (about 0.3 mm) when adjusted to the same current-density as the reference tube gave spectra so nearly like those of the reference tube that no certain differences could be detected.

End-on effect.—To test whether we were dealing with saturated radiation in using the light from the side of a 2.6 mm capillary, we compared it with an end-on tube with a capillary portion 3.2×32 mm. This gave for relative intensities:

	α	β	γ	a	b	c
$\frac{\text{End-on}}{\text{Side-on}}$	1	1.35	1.58	4.37	4.37	4.39

These are relative to α, since there was an indeterminate constant factor involved. This apparently great departure from saturation we found to be due to a difference in the electrical conditions as the current leaves a capillary. We later obtained similar readings (not quite as high) from one end of a capillary viewed from the *side*.

Spark, capacity, and inductance.—The disruptive discharge was studied in considerable detail with various tubes containing gas at 1, 5, and 10 mm pressure. Two identical tubes were adjusted to 15 m.a. current, but on independent circuits, and then the discharge in one of them made disruptive, the reference tube remaining at 1 mm and 15 m.a. in each case. Some typical results are given below, the three primary readings being combined, as they remained equal throughout to within the uncertainty of measurement.

Pressure, 1 mm	α	β	γ	P
Spark : No Spark	0.59	0.56	0.60	0.73
Spark + C : No Spark	0.191	0.118	0.063	0.095
S + C + I : S + C	0.22	0.13	0.110	0.191
5 : 1 mm				
Spark : No Spark	1.0	0.80	0.74	0.90
S + C : No Spark	1.0	0.35	0.23	0.25
S + C + I : S + C	0.76	0.86	1.22	1.31
10 : 1 mm				
Spark : No Spark	2.30	1.20	0.90	1.10
S + C : No Spark	5.88	2.55	1.00	0.87
S + C + I : S + C	0.50	0.60	1.00	1.50
Porcelain 1 : 1 mm 200 m.a.				
S + C : No S	0.79	0.64	0.52	0.46

These results show the same selective effects as were obtained with heavy steady currents. In the first case for example, the effect of capacity was to give α, β, and γ the ratio 3 : 2 : 1 while P lies between β and γ. These agree well with the values for a current of 200 to 250 m.a. in the porcelain tube. On the other hand in the last case where a heavy current (200 m.a.) was used with the condenser, the

effect was much less marked, about equivalent to raising the current to 300 m.a. The apparent weakening of the discharge was due to the longer interval in which no current is passing. The effect of inductance appears to be merely to neutralize part of the capacity effect. The secondary lines α, β, and γ are affected by both capacity and inductance in the order named, α most and β least.

THEORY

Before going into the theory of radiation from conducting gases, it may present our results in a clearer light to compare them with corresponding results for radiating solids. For many substances it is well known that the radiation in the visible spectrum may be closely represented as a function of wave-length and temperature by the Wien-Paschen function

$$E=c_1\lambda^{-n}e^{-c_2/\lambda T}.$$

For a perfect radiator $n=4.96$ or 5, for platinum about 6, and for tungsten about 7, while c_2 is in the neighborhood of 15,000 when wave-lengths are expressed in microns (μ) and temperatures in Centigrade degrees absolute.

The relative radiation, using that at a fixed temperature T_0 as a standard, would be

$$\left(\frac{E}{E_0}\right)_\lambda=e^{-\frac{c_2}{\lambda}\left(\frac{1}{T}-\frac{1}{T_0}\right)},$$

while the relative intensities of the radiation of two different wave-lengths would be

$$\left(\frac{E_1}{E_2}\right)_T=\left(\frac{\lambda_1}{\lambda_2}\right)^{-n}e^{-\frac{c_2}{T}\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)},$$

If hydrogen obeyed this radiation law our results (p. 67) would give

	n	c_2/T
For the primary spectrum..	36.1	26,700
For the secondary spectrum	159	89,600

values farther from those of a perfect radiator than for any solid yet studied, but yet of the proper sign and not impossible values.

We found further

$$\frac{S}{S_0}=\left(\frac{P}{P_0}\right)^m \text{ where } m=c\left(\frac{1}{\lambda_0}-\frac{1}{\lambda}\right),$$
$$=e^{m\log P/P_0}$$

which again is in accord with known radiation laws, provided P/P_0 is expressible as a function of free internal energy alone.

Consider a column of conducting gas consisting of neutral atoms, positive ions, and negative electrons. When a steady current is flowing, the total radiation from the gas will be equal to the power-supply, gradient times current (X/i). This transformation of energy is undoubtedly accomplished by the charged particles taking energy from the current by falling down the gradient and then giving it up by impact to be radiated away or to cause fresh ionization. The problem is to determine the amounts of energy involved in the various kinds of collision under different conditions of current and gas density.

With 50 volts per cm in hydrogen at 1 mm pressure the negative electrons (correcting the path for small size and high speed by the factor $4\sqrt{2}$) move with a mean velocity over 10,000 times as great as the neutral atoms and 100 times as great as the positive ions. Hence the energy of collision is determined chiefly by the velocity of the negative electrons, and we have to consider four types of collision of these electrons with:

1. Neutral atoms producing perturbations only,
2. Neutral atoms producing an additional electron,
3. Positive ions resulting in recombination,
4. Positive ions producing perturbations only.

Let ν be the average number of times an electron hits either a neutral atom or a positive ion in a second. If N is the number of both of these and n the number of the latter in a cubic centimeter, then $\nu(N-n)\ N$ is the collision frequency of an electron with whole atoms and $\nu n/N$ with positive ions. These frequencies multiplied by N is the number of electron collisions in each cc of gas per second.

Each collision of an electron with an atom will produce ionization or not, according to how it strikes and the velocity with which it strikes. To obtain the collision frequency of each of the above four classes we must then integrate to or from certain critical velocities and introduce an arbitrary factor depending upon how the electron strikes. If we assume a hard smooth spherical atom we must resolve the motion of the electron normal to the surface. If, however, the atom be rough or soft, the motion would have its full effect. In the first case a would involve a surface integral, in the second a is unity. As we are

here concerned only with the relation of radiation to current and pressure, we need not go farther into the matter.

Of n paths, those lying between s and $s+ds$ are

$$dn=\frac{n}{s_0}e^{-s/s_0}dS$$

s_0 being the mean path, hence,

$$\int_0^{s_c} dn = n(1-e^{-s_c/s_0})$$

$$\int_{s_c}^{\infty} dn = ne^{-s_c/s_0}\,.$$

The frequencies of collision of the four classes are then

$$\nu_1=a_1 vn\frac{N-n}{N}(e^{-s_1/s_0}-e^{-s_2/s_0})$$

$$\nu_2=a_2 vn\frac{N-n}{N}e^{-s_2/s_0}$$

$$\nu_3=a_3 vn\frac{n}{N}(1-e^{-s_3/s_0})$$

$$\nu_4=a_4 vn\frac{n}{N}e^{-s_3/s_0}\,.$$

The critical paths S_1, S_2, and S_3 correspond with the critical velocities u_1, u_2, and u_3; u_3 being the limiting velocity beyond which recombination will not occur, u_2, a velocity below which ionization will not occur, and u_1, a velocity below which radiation will not be excited.

For steady current $(i=\Sigma neu)$ the rates of recombination and ionization must be equal, hence $\nu_2=\nu_3$ and hence the total ionization is determined in terms of current-density.

The energy of collision in each of the four classes of impact will be the integral of $\frac{1}{2}mu^2dn$ between the same limits as before. Remembering that $u^2=2Xe/mS$ and that $evn=i/s_0$, we have in the four cases:

$$E_1=Xia_1\frac{N-n}{N}\left[\left(1+\frac{s_1}{s_0}\right)e^{-s_1/s_0}-\left(1+\frac{s_2}{s_0}\right)e^{-s_2/s_0}\right]$$

$$E_2=Xia_2\frac{N-n}{N}\left(1+\frac{s_2}{s_0}\right)e^{-s_2/s_0}$$

$$E_3=Xia_3\frac{n}{N}\left[1-\left(1+\frac{s_3}{s_0}\right)e^{-s_3/s_0}\right]$$

$$E_4=Xia_4\frac{n}{N}\left(1+\frac{s_3}{s_0}\right)e^{-s_3/s_0}\,.$$

This is the energy imparted to the radiators in a manner capable

of producing radiation. If this energy cannot easily be transformed into heat energy, the energy received will be the energy radiated as light; experiment must tell us which forms of radiators are most active.

In each of the four cases the predominant term is Xi, the product of gradient and current, i. e., the rate of total energy-supply. The final exponential term is constant except when a variation in density varies the mean path S_o. With increase in the current, X decreases slightly to a minimum and then increases. n would be proportional to i but for the slight variation in X and is very small in comparison with N even for large currents.

The collision results in a whole atom in the first and third cases, in a positive ion in the second and fourth. If now the primary spectrum comes from the whole atom and the secondary from the positive ion, as the great majority of experimental evidence indicates, we are still unable to say whether the chief energy-supply is due to recombination, ionization, or from being "shot up." But if further the secondary is nearly proportional to the square of the primary, as we observed, then most of the spectral radiation must come from the first and fourth types of collision, that is, where atoms and positive ions are shot through by electrons without resulting ionization or recombination.

In the second case (ionization) it is plausible that the energy of impact should be quite used up in tearing the extra electron loose from the atom, but in the third case, it is not easy to see why recombination should not produce radiation.

The effect of increased pressure is to diminish the free path, S_o, and hence to increase the intensity of the primary spectrum (current remaining constant) and decrease the secondary as observed. Accompanying the increase in pressure, there is a slight increase in X and in n acting as a slight compensation for the decrease in s_o.

It is easy to see why there should be a selective effect in the secondary spectrum for heavy but not for weak currents. Since the velocity and energy of impact depend only upon the potential-gradient, an increased current will result only in an increased number of impacts until the current becomes so large that the gradient increases with it. Our results then indicate that the slower modes of vibration take up the larger share of the increased energy of excitation.

Bureau of Standards
November 30, 1909

MEASUREMENTS OF WAVE-LENGTHS OF STANDARD IRON LINES

By P. EVERSHEIM

In this paper I give the measurements of standard wave-lengths in the spectrum of iron. The paper will appear *in extenso* in a forthcoming number of the *Annalen der Physik.*

WAVE-LENGTHS OF STANDARD IRON LINES

Eversheim	Fabry and Buisson	Differences E. − F. & B.	Mean Error	Eversheim	Fabry and Buisson	Differences E. − F. & B.	Mean Error
4282.408	.407	+ .001	0005	5266.569	....	+ .001	.....
4315.089	.089	.000	.0005	5302.316	.316	.000	.0005
4352.741	.741	.000	.0005	5324.196	.195	+ .001	.0005
4375.934	.935	− .001	.0006	5371.493	.498	− .005	.0008
4427.313	.314	− .001	.0006	5405.780	.780	.000	.0010
4466.557	.554	+ .003	.0005	5434.524	.530	− .006	.0005
4494.571	.572	− .001	.0004	5455.611	.616	− .005	.0008
4528.622	....	......	.0004	5497.523	.521	+ .002	.0006
4547.853	.854	− .001	.0006	5506.785	.783	+ .002	.0007
4592.658	.658	.000	.0005	5569.636	.632	+ .004	.0006
4602.948	.944	+ .004	.0004	5586.773	.770	+ .003	.0004
4647.441	.437	+ .004	.0004	5615.662	.658	+ .004	.0008
4691.419	....	......	.0006	5658.838	.835	+ .003	.0010
4707.292	.287	+ .005	.0007	5763.013	.013	.000	.0008
4736.785*	.785	.000	.0010	5826.294 *Ba*	....	......	.0003
4736.787	....	+ .002	.....	5857.759 *Ni*	.759	.000	.00010
4754.049 *Mn*	.046	+ .003	.0007	5892.881 *Ni*	.881	.000	.0005
4789.658	.657	+ .001	.0010	5971.715 *Ba*	....	......	.0006
4823.523	.521	+ .002	.0006	5997.102 *Ba*	....	......	.0005
4859.758	.756	+ .002	.0006	6065.493	.493	.000	.0007
4878.224	.226	− .002	.0008	6108.121 *Ni*	....	......	.0004
4903.327	.324	+ .003	.0004	6191.568	.569	− .001	.0005
4919.007	.006	+ .001	.0003	6230.736	.732	+ .004	.0005
4966.105	.104	+ .001	.0007	6318.028	.029	− .001	.0007
5001.885	.880	+ .005	.0008	6335.342	.343	− .001	.00010
5012.074	.072	+ .002	.0006	6393.613	.612	+ .001	.0006
5049.827	.827	.000	.0006	6430.862	.859	+ .003	.0006
5083.346	.343	+ .003	.0008	6494.994	.994	.000	.0007
5110.414	.415	− .001	.0008	6546.252	....	......	.00012
5167.491	.492	− .001	.0006	6592.931	....	......	.0008
5191.473	....	......	.0010	6678.008	....	......	.00010
5232.958	.958	.000	.0005	6750.162	....	......	.00010
5266.566†	.568	+ .002	.0020	6945.223	....	......	.00025
5266.569*	....	+ .001	.....				

* With grating, referred to $\lambda = 4707.287$ and $\lambda = 4789.657$.

† With grating, referred to $\lambda = 5232.958$ and $\lambda = 5302.316$.

I employed the method of MM. Fabry and Buisson, as published in their paper, "Mesures de longueurs d'onde pour l'établissement d'un système de repères spectroscopiques."[1] Where feasible I measured the lines for which they had published the wave-lengths. The three places of decimals of their determinations are given in the second column, while the differences of our values[2] are found in the third column. The fourth column contains the mean probable errors of my measurements in units of the fourth place of decimals of the Ångström unit.[3]

[1] *Journal de Physique* (4), **7**, 169, 1908; *Astrophysical Journal*, **28**, 169, 1908.

[2] Occurring in the third decimal.

[3] The wave-lengths below λ 4282 will be published as soon as the measurements are finished.

BONN, PHYSICAL INSTITUTE OF THE UNIVERSITY
October 18, 1909

THE ANALYSIS OF THE PRINCIPAL MERCURY LINES BY A DIFFRACTION GRATING AND A COMPARISON WITH THE RESULTS OBTAINED BY OTHER METHODS

By HENRY G. GALE and HARVEY B. LEMON

In 1892 Professor Michelson[1] discovered that many spectral lines are accompanied by satellites. The structure of the lines was deduced from the form of the visibility-curves, and the limitations of the method were fully recognized.

In 1899 Fabry and Perot[2] announced similar results, obtained with their form of the interferometer. Since the invention of the echelon,[3] further investigations in this field have been made by numerous observers.[4] In 1904 Barnes[5] invented an ingenious form of interferometer and analyzed a number of bright lines. Lummer and Gehrcke,[6] in 1903, published results obtained with their interference plate, and this work has been extended by Gehrcke and von Baeyer.[7]

There has been a certain amount of concordance in the results obtained by various observers, and not a little lack of agreement, caused in some instances by the use of different sources, as in the well-known case of the green cadmium line,[8] and in others, no doubt, by false lines due to instrumental imperfections.

[1] *Phil. Mag.* (5), **34**, 280, 1892.

[2] *Ann. de Chimie et de Physique* (7), **16**, 115, 1899.

[3] A. A. Michelson, *Astrophysical Journal*, **8**, 37, 1898.

[4] Gray and Stewart, *Proc. Royal Soc.*, **72**, 16, 1904; R. A. Houston, *Phil. Mag.* (6), **7**, 456, 1904; L. Janicki, *Annalen der Physik*, **19**, 36, 1906; **29**, 833, 1909; B. Galitzin, *Bull. de l'Acad. Impériale des Sciences de St. Pétersbourg*, 159, 1907.

[5] James Barnes, *Astrophysical Journal*, **19**, 190, 1904; *Phil. Mag.* (6), **7**, 485, 1904.

[6] Lummer and Gehrcke, *Annalen der Physik*, **10**, 457, 1903.

[7] Gehrcke and von Baeyer, *Annalen der Physik*, **20**, 267, 1906; O. von Baeyer, *Astrophysical Journal*, **25**, 267, 1907; *Verh. der Deutsch. Phys. Gesell.*, **9**, 84, 1907; *ibid.*, **10**, 733, 1908; and *Phys. Zeit.*, **9**, 831, 1908.

[8] M. Hamy, *C. R.*, **130**, 489, 1900; **130**, 700, 1900; Fabry and Perot, *C. R.*, **130**, 654 (note), 1900; *Astrophysical Journal*, **16**, 36, 1902; Louis Bell, *ibid.*, **15**, 157, 1902; **18**, 192, 1902; J. Hartman, *ibid.*, **18**, 187, 1903; C. Fabry, *Astrophysical Journal*, **19**, 116, 1904.

In the spring of 1909 a comparison of the structure of the green mercury line, as given by three different echelons, with that given by a grating recently ruled by Professor Michelson was made by one of us.[1] The constants of the echelons were only roughly determined, but the photographs taken showed conclusively that the grating gave results comparable with those of the echelons. The ease of manipulation of the grating and the absence of ambiguity due to conflicting adjacent orders made its use a very obvious advantage.

Through the kindness of Professor Michelson we have been able to photograph the principal lines of mercury with one of the gratings ruled by him. The grating used has a ruled surface $6\frac{1}{2}$ inches by $2\frac{7}{8}$ inches (16.5 cm by 7.3 cm). It was mounted in the Littrow form with a Brashear lens of 20 ft. (6.1 m) focal length. This particular grating is exceptionally bright in the higher orders on one side, and satisfactory photographs could be obtained in the fourth order in from five minutes to forty minutes, depending on the line sought.

It is well known that in certain cases the relative intensities of the satellites is different with different sources, and we have therefore thought it wise to use a commercial Cooper-Hewitt lamp, since this is a very satisfactory source and one easily available for comparison by others.

Figs. 1 to 4 show diagrammatically the results of various investigators. Tables I to IV give the corresponding values of the wave-lengths. The letters accompanying the diagrams and tables have the following significance: M., Michelson;[2] F. and P., Fabry and Perot;[3] v. B., von Baeyer;[4] J., Janicki;[5] G., Galitzin;[6] S., Stansfield;[7] and Gr., the grating results obtained by us. Intensities are

[1] Paper read by Mr. Lemon before the American Physical Society at the November meeting, 1909, at the University of Illinois.

[2] A. A. Michelson, *Phil. Mag.* (5), **34**, 280, 1892.

[3] Fabry and Perot, *Ann. de Chimie et de Physique* (7), **16**, 115, 1899. For their last values for the green line see Zeeman, *Astrophysical Journal*, **15**, 218, 1902.

[4] O. von Baeyer, *Verh. der Deutsch. Physik. Gesell.*, **10**, 733, 1908; also *Phys. Zeit.*, **9**, 831, 1908.

[5] L. Janicki, *Annalen der Physik* (4), **19**, 36, 1906; *ibid.*, **29**, 833, 1909.

[6] B. Galitzin, *Bull. de l'Acad. Impériale des Sciences de St. Pétersbourg*, 159, 1907.

[7] H. Stansfield, *Phil. Mag.* (6), **18**, 371, 1909.

assigned in the tables in accordance with the methods of the various authors.

TABLE I. λ 5790

M.	F. and P.	v. B.	J.	G.	Gr.
+ .24 $\frac{1}{10}$ + .13 $\frac{1}{10}$ − .12 $\frac{1}{5}$	− .130 very weak	+ .228 3 + .133 2 − .122 1 − .180 weak	+ .230 $\frac{1}{7}$ + .168 $\frac{1}{10}$ + .132 $\frac{1}{7}$ + .084 $\frac{1}{5}$ − .119 $\frac{1}{5}$ − .187 $\frac{1}{10}$ − .251 $\frac{1}{10}$	+ .228 3 + .169 6 + .132 2 + .086 5 − .121 1 − .190 4	+ .229 2 + .135 2 − .119 1 − .184 3 − .931 4 − .998 3

TABLE II. λ 5769

M.	F. and P.	v. B.	J.	G.	Gr.
± .043 $\frac{1}{5}$	+ .048	+ .044 1 − .048 2	+ .048 2 − .052 2 − .114 3	+ .042 2 − .049 1	+ .040 1 − .044 2

TABLE III. λ 5461

M.	F. and P.	v. B.	J.	G.	S.	Gr.
+ .13 $\frac{1}{10}$ + .10 $\frac{1}{4}$ (+ .01) − .07 $\frac{1}{10}$ (− .23)	+ .136 $\frac{1}{6}$ + .082 $\frac{1}{4}$ + .008 $\frac{1}{2}$ − .052 $\frac{1}{5}$ − .076 $\frac{1}{7}$ − .224 $\frac{1}{3}$	+ .211 6 + .125 3 + .082 1 − .024 1 − .049 5 − .068 3 − .101 4 − .237 2	+ .133 $\frac{1}{8}$ + .088 $\frac{1}{3}$ − .066 $\frac{1}{7}$ − .099 $\frac{1}{10}$ − .232 $\frac{1}{6}$	+ .129 4 + .085 3 − .047 6 − .068 2 − .099 5 − .236 1	+ .216 2 + .131 4 + .087 1 − .068 3 − .097 3 − .232 1	+ .217 4 + .130 3 + .083 2 − .054 3 − .094 3 − .233 1

TABLE IV. λ 4358

M.	v B.	J.	G.	G.′	Gr.
± .17 $\frac{1}{10}$ (± .019)	+ .185 3 + .114 5 + .044 5 + .028 6 + .019 5 − .017 1 − .045 7 − .093 4 − .107 4 − .159 2	+ .121 $\frac{2}{3}$ + .105 $\frac{2}{3}$ + .043 $\frac{1}{4}$ + .020 $\frac{1}{6}$ − .023 1 − .052 $\frac{1}{7}$ − .097 $\frac{2}{3}$ − .112 $\frac{2}{3}$	(+ .131) 2′ + .126 2 (+ .118) 2″ + .053 3 + .027 4 − .092 1	+ .194 + .118 + .053 + .027 − .092 − .155	+ .194 2 + .118 3 + .040 2 − .088 4 − .155 1

The yellow lines, λ 5790 and λ 5769, are shown in Figs. 1 and 2, respectively, the green line, λ 5461, in Fig. 3, and the violet line, λ 4358, in Fig. 4. Figs. 5 to 8, Plate VI, are made from our photographs, enlarged about eighteen diameters laterally, and given vertical motion to smooth out the grain of the plates. Some of the detail of the original plates is of course lost. The faint satellite of λ 5790

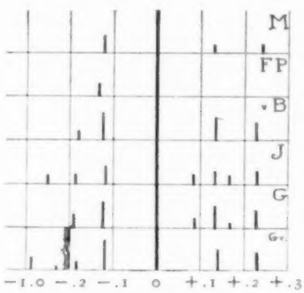


FIG. 1

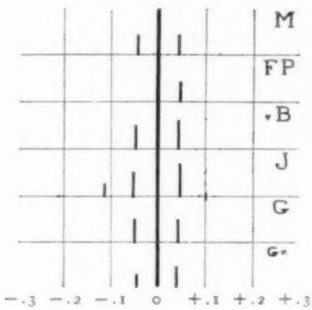


FIG. 2

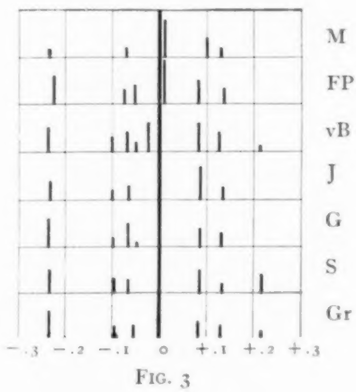


FIG. 3

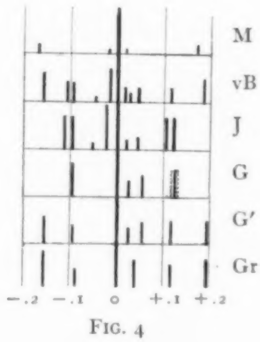


FIG. 4

at $-.931$ shows plainly on the original negative. The main line of λ 5769 is narrow and sharp and its satellites are broad and fuzzy. The satellites of λ 5461 at $-.054$ and $-.094$ are clearly resolved on our original negatives. Visually the satellities at $+.083$ and $+.130$ are separated by approximately three times the width of the lines in the fourth order. The satellite at $+.217$ is definite and certain with the Cooper-Hewitt source. It appears possible that it is a double in the small arc, the weaker component being at $+.217$ and a slightly

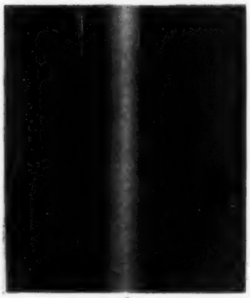
stronger one at about +.170. We are not prepared to make a final statement on this point at present. The effect is magnified in the reproduction, probably on account of the trailing of a dust particle across the plate during the vertical motion. In the case of λ 4358 the satellite at +.040 is clearly separated from the main line on some of our best plates, and shows plainly as a region of diminished brightness on all of the fourth- and fifth-order plates, but in the reproduction it appears to overlap and merge into the main line.

Seed's Panchromatic and Cramer's Spectrum plates were used for the yellow, Cramer's Medium Isochromatic for the green, and Seed's "27" for the violet. Our plates were measured on a Zeiss comparator, and each value is the mean of a number of separate determinations. All should be correct to within a few thousandths of an Ångström unit.

Aside from the very satisfactory results obtained with the grating the most interesting feature of the work was the verification, to such a remarkable degree, of the results obtained by Professor Michelson in 1892. It should be remembered that those results were absolutely the first in this field, that they were obtained by a method requiring such a high degree of personal skill that no one since has used it with success, and that the whole investigation was, in a sense, incidental to the more important task of determining the number of wave-lengths in the meter.

It does not seem to be generally understood that it is possible to determine whether a satellite lies on the red or violet side of a line with the Michelson interferometer. Although Professor Michelson made no attempt to do this, he pointed out very clearly in the original article how it may be done. The fringes at a minimum will lag behind a perfectly definite fractional part of a fringe if the satellite is on the violet side of the main line, and they will be a definite fractional part of a fringe ahead at a minimum if the satellite is on the red side. If the visibility-curve indicates satellites when there is no such shift at a minimum, there must be two satellites, equally distant from the main line, one on each side. By comparing the fringes with those of a line which has no satellites, like the red line λ 6438 of cadmium, the so-called phase-curve may be plotted, i. e., a curve in which the differences of path of the interfering beams are

PLATE VI



Scale: −0.1 0 +0.1

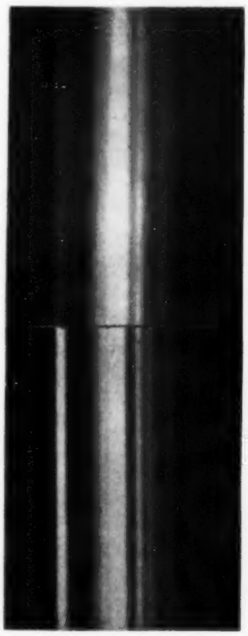
FIG. 5.—λ 5769

Scale: −1.0 −0.2 0 +0.2

FIG. 6.—λ 5790

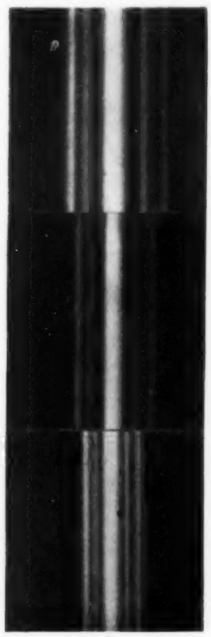
Small Arc

Cooper-Hewitt



Scale: −0.2 0 +0.2

FIG. 7.—λ 5461



5th order

4th order

3rd order

Scale: −0.2 0 +0.2
3rd order

FIG. 8.—λ 4358

abscissae and the shift of the observed fringes due to satellites are ordinates. The visibility-curve and the phase-curve together give a definite solution, without ambiguity.

Although Professor Michelson's value for the distance of the satellite of λ 5769 has often been quoted, it does not seem to have occurred to anyone to re-examine the visibility-curve. The visibility-curves of λ 5769 and λ 5790 are reproduced in Fig. 9. A glance is sufficient to show that the minima of λ 5769 are a little more than twice as far apart as those due to the principal satellite of λ 5790. The satellite of λ 5769 must therefore be a little less than half as far from its main line as the principal satellite of λ 5790. A recomputation gives its distance as .043 Å. U. instead of .019 Å. U. as originally given. It seems odd that none of those who have quoted this latter value has noted the discrepancy.

It may have escaped the notice of some of the recent workers in this field that there is a faint line $-.998$ Å. U. from λ 5790. A faint satellite accompanies it at $-.931$. The constant of the echelons used by Janicki and Galitzin is about .543 at this wave-length, and unless light from these lines were excluded they would appear at $+.088$ and $+.155$. We have detected a line of intensity about 1/100 of that of the main line at $+.085$. On account of its great faintness, however, we regard it as possible that the line measured by Janicki and Galitzin as at $+.085$ may be due to the line at $-.998$, which would appear at $+.088$. We have been unable to detect any line near $+.168$ and regard it as possible that the line given by them there may be due to the faint line at $-.931$, which would appear to be at $+.155$. The discrepancy in wave-length is rather large but the line is exceedingly faint and hard to measure accurately.

Professor Michelson's visibility-curve for λ 5461 is reproduced in Fig. 10. He indicates a satellite very close to the main line on each side. He might equally well have chosen to regard them as being both on the same side. We have chosen this interpretation and have computed from the visibility-curve the distance of this satellite from the main line. The rise in the visibility-curve at about 315 indicates clearly that the main line is a close double. The calculation indicates a satellite at .010 which agrees with the observations of Fabry and Perot, who give a satellite at $+.008$, and of Barnes, who gives one

at + .01. We have added this satellite to the diagram, Fig. 3, placing it on the positive side. Workers in this field seem to be pretty well agreed that the main line is a close double, resolvable only with very high powers, and when the vapor-density is very low. Incidentally it may be pointed out that the visibility-curves as obtained with the

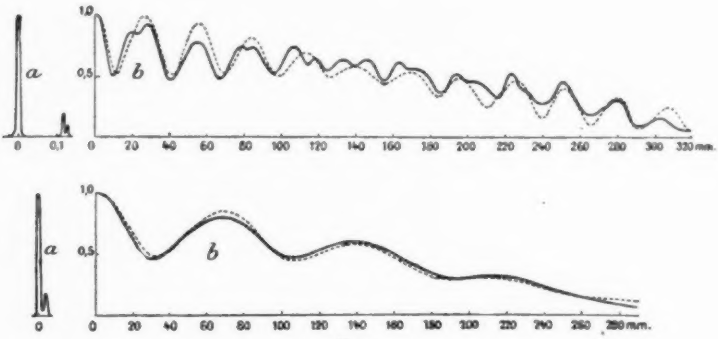


FIG. 9

Michelson interferometer form the only means of resolving lines which actually merge together, or of getting the distribution of light within a line. This, it will be recalled, was done in the case of H_a, λ 6563, long before the line was admitted to be double by many spectroscopists. It should also be borne in mind that an apparent doubling of a line may be due to a reversal. It should however as a

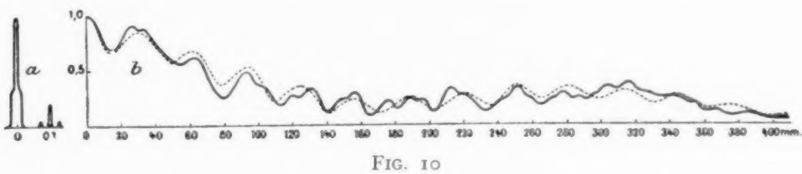


FIG. 10

rule be a simple matter to test whether a line is a true double or a reversed line. In the former case the separation should be most marked at low vapor-densities. In the latter case the apparent separation should increase with the vapor-density.

In the case of Fig. 10 it will be noticed that there are faint minima at roughly 112, 123, 140, 152, 164, 180, 190, 200, etc., which are not present in the dotted curve. These minima indicate that in the tube

used by Professor Michelson there was a faint satellite at a distance a little more than twice that of the main satellite. A calculation from the curve gives its distance as .23 Å. U., and it is undoubtedly the same as the line observed by us at $-.233$ Å. U. We have therefore added it also to the diagram, Fig. 3. Plate VI, Fig. 7, shows the variation of the relative intensity of this satellite when the source is a small mercury arc, instead of the Cooper-Hewitt lamp. In the Cooper-Hewitt lamp (the lower spectrum) this satellite is the principal one, while in the small mercury arc there are several other satellites of equal or of greater strength. The intensity of this satellite seems to be especially sensitive to a change in conditions, and in the tubes from which the visibility-curves were plotted it was undoubtedly one of the fainter satellites, and was therefore ignored.

The violet line λ 4358 is not easy to observe visually, but the results obtained in 1892 by Professor Michelson are again noteworthy. He indicates a satellite at .17, "and two fainter ones near the main line." If we put half of the main satellite on each side and the two fainter ones as indicated, we get the result indicated in Fig. 4. The considerable number of lines found by some observers may be the result of reversals as it is well known that in general the tendency to reverse increases toward the violet. It should also be borne in mind that great care must be taken to have the lines in sharp focus on the photographic plate or strange results will be obtained with this line as with others. Possibly also some of the optical parts used may have been sufficiently accurate for the yellow and green regions but not in this region of shorter wave-length and greater refrangibility. An instrument like the Lummer-Gehrcke plate which reflects the light would be especially sensitive to an error in the surfaces and an error which might be negligible in the green and yellow might produce serious results in the violet. The very excellent agreement of our results with those of von Baeyer for the longer wave-lengths, and the relatively poor agreement at λ 4358 suggest some possible source of error. It should be borne in mind however that the satellites may have a very different appearance in different forms of tubes. In the small arc referred to above, the five satellites of λ 4358 are all of nearly equal intensity.

The line at λ 4358 also brings out the greatest disadvantage of the echelon and interference plate, ambiguity due to overlapping orders. Galitzin describes his satellite at +.126 as very strong, and says further that it "erscheint zuweilen doppelt und bestehend aus zwei nahen Linien." On some of his plates he measured the position of these two lines, getting their wave-lengths as +.118 and +.131. We have found no line at +.126, but have a line at +.118. Galitzin gives his constant as .286 at this wave-length, and the line at +.131 might equally well have been taken as at −.155, in exact agreement with our line at −.155. He also gives the line at −.092 as very strong and in regard to it remarks, "Bei dem trabanten B_1, kann man ebenfalls eine Verdoppelung vermuthen, aber die Erscheinung ist sehr undeutlich," etc. We have a satellite at −.088 and another at +.194 which is exactly the wave-length which would be assigned to this satellite if it were regarded as on the positive side. We therefore regard Galitzin's line at −.092 as made up of our two lines, −.088 and +.194. Furthermore, the mean of his two lines at +.053 and +.027 is +.040, exactly the position of one of our satellites. We have therefore rearranged Galitzin's satellites under G′, Fig. 4 and Table IV, and the agreement with our results is excellent.

We do not feel that our results furnish the last word as to the resolution of the principal lines of mercury with gratings. When larger gratings become available, and a longer focus lens for the Littrow mounting, and when a mounting designed especially for steadiness and constancy of temperature is used, it may be possible to resolve into doubles some of the lines reported by us as single. Thus there seems to be a triplet on the violet side of λ 5461. This was indicated quite clearly in the echelon results obtained by Mr. Lemon, referred to above. Our line at −.054 might well be a blend of the lines given by Galitzin and von Baeyer at −.048 and −.068. The group has a fuzzy appearance with the grating and it is difficult to resolve the lines clearly on photographs. We feel quite confident, however, that all the lines reported by us are real, and that, aside from the possible resolution of some lines into doubles, there are no others in the Cooper-Hewitt source unless their intensity is of the order of 1/100 of that of the main lines.

In conclusion we desire to express our sincere thanks to Professor Michelson for the use of the splendid grating, and of his private laboratory in which all the photographs were taken.

Ryerson Physical Laboratory
The University of Chicago
January 1910

Minor Contributions and Notes

THE SIZE OF METEORS

In the November number of this *Journal* (p. 318), Professor Fabry criticizes my statement, published in the June number, as to the probable size of meteors. There are several reasons for the difference in our results, but the chief one depends on the fact that he assumes the intrinsic brightness of a meteor to be that of the cup of an electric arc, while I have assumed it to equal the light given out by the carbons in a horizontal direction. This light varies in different parts of the carbons, but I assumed an illuminated area of one-half inch in diameter, or practically one square centimeter (see *Harvard Annals*, **41**, 141). Assuming a horizontal illumination of 250 candle-power, the ratio of the intrinsic brilliancies that we have adopted stands at about 80 to 1.

In my investigation I chose the horizontal brilliancy because the most direct method of comparing a meteor with an arc light seemed to be to measure the latter photometrically from a known distance, expressing its brightness directly in stellar magnitudes. Three arc lights situated at a distance of about 2.5 km were carefully measured, and were found to give unexpectedly uniform results. This was twelve years ago, when the open arcs were used. It was concluded that at that distance their brightness was that of a star of magnitude -1.

That the temperature of a meteor is not very different from that of the carbons is shown by the fact that when about equally brilliant their colors are approximately the same, some meteors being more blue, and some more yellow, than the artificial source. However, just as in photographing an electric arc, while what we see on the ground glass are the luminous carbons, yet what we photograph is chiefly the blue arc between them; so with meteors, when we photograph their spectra during flight, what we find is a luminous gas, not an incandescent solid. This is very different from the case of an extremely hot body like the sun, where the light from the incandescent

gases is concealed by the glare from the incandescent solid or liquid particles.

No accurate determination of the size of a falling star is possible by any means, but if we reduce the estimated luminous area of the incandescent carbons to ten square millimeters, or one-tenth the value formerly adopted, the corresponding diameter of a falling star of the third magnitude would still be 5 or 6 centimeters, which would imply a mass to be measured in hundreds of grams, instead of milligrams, as usually stated.

The minimum diameter of a third-magnitude meteor as computed by Professor Fabry should be 5.42 mm, and not 25.4 as printed, evidently through a typographical error.[1] This result is based on his determination that a 0-magnitude star is equivalent to 2.1×10^{-6} candle-power at one meter distance. In the *Harvard Annals*, **61**, 69, it is shown from comparisons of *Arcturus* with a distant standard lamp, that a 0-magnitude star is equivalent to one candle-power at a distance of 526 meters. From this we deduce that a 0-magnitude star is equivalent to 3.61×10^{-6} candle-power, a result nearly twice as large as that given by Professor Fabry. This would lead to a diameter for a meteorite of the third magnitude of 7.0 mm. A fireball of the -2 magnitude would have a diameter of 7 cm. To suppose that such an insignificant body could emit a luminous atmosphere, such as sometimes occurs, measuring 1.5 km in diameter, and 15 to 50 km in length, is manifestly absurd.[2]

WILLIAM H. PICKERING

[1] This typographical error is corrected on p. 400, December 1909.—EDS.

[2] C. C. Trowbridge, *Astrophysical Journal*, **26**, 95, 1907.

Reviews

Der Bau des Fixsternsystems. Von Dr. Hermann Kobold. Braunschweig: F. Vieweg und Sohn, 1906. 8vo, pp. 256; Figs. 22. M. 4.

As a compendium of the results of researches made into the realms of the cosmogony of our visible stellar universe, this book is excellent.

The subject of the probable structure of the visible universe has always interested thinkers, whether they be astronomers or not, and many have been the conjectures, based on speculation, as to the ultimate destination of the stars and the laws governing their motions.

With the advent of astronomy of precision, with the discovery of proper motion, with the employment of spectrum analysis, fields hitherto closed have opened to the modern astronomer, so that speculation is giving way to scientific fact. But the leanness of material and its large probable errors still leave a wide range of interpretation of the deduced results, so that we must not be surprised if the views of various investigators differ to an alarming extent.

Kobold's *Bau des Fixsternsystems* is an attempt to gather and classify the results attained by various investigators, giving each its worth.

In Parts I and II the author gives brief summaries of the instruments and methods by which we have arrived at our conclusions as to the composition, disposition, and motion of the stars.

With Part III begins the exposition of the results of various investigators on the varied questions involved in the investigation of our universe, with comments and investigations by the author.

Thus the works of Kapteyn, Schoenfeld, Bakhuyzen, Ristenpart, Plassmann, the excellent works of Seeliger, and many others too numerous to detail, are all set forth, making it an excellent reference book. Add to this the frequent references to various publications in connection with every branch of the subject, and the book becomes the more valuable.

There are many illustrative tables and diagrams throughout the text, and at the end a table of large parallaxes, and another of proper motions greater than $0''.5$.

As to the views adopted by the author, and his conclusions drawn therefrom, they may well be doubted in the light of more recent work upon the subject, especially as to the more or less random motion of the stars.

Benjamin Boss

A Treatise on Spherical Astronomy. By SIR ROBERT BALL. Cambridge: The University Press, 1908; New York: G. P. Putnam's Sons. Pp. xii + 506. Price $3.75.

"By spherical astronomy I mean that part of Mathematical Astronomy which lies between the vast domain of Dynamical Astronomy on the one hand and the multitudinous details of Practical Astronomy on the other." Such is the author's definition of his subject-matter and it is coupled with the statement that his treatise is prepared for the use of the student familiar with the ordinary processes of plane and spherical trigonometry and having some knowledge of analytic geometry and the infinitesimal calculus. The reader thus defined will usually be a university undergraduate and the book is obviously addressed to the English university student. Before him there is spread with mathematical elegance a larger variety of subject-matter than is to be found in any similar treatise within our ken, e. g., the measurement of time, transformation of spherical co-ordinates, projection of maps, refraction, parallax, precession, aberration, eclipses, solar, lunar, and planetary phenomena, with excursions into celestial mechanics, the method of least squares, and the theory of instruments; the whole supplemented by a noteworthy collection of exercises and problems largely chosen from the mathematical tripos and other university examinations.

It is obviously unfair to judge such a work by the criteria applicable to the treatises of Chauvenet, Brünnow, or Newcomb, and yet it should not be left unsaid that, from the standpoint of the astronomer who desires a book of reference, or for the student who seeks to lay the foundation of practice in the arts of the astronomer, the book appears to the reviewer inadequate through the omission of matter too important to be ignored even in an elementary treatise. In this respect a single chapter must suffice in illustration of characteristic limitations of the work. In the twenty-nine pages devoted to atmospheric refraction, while much space is given to matter of little more than historic interest, such as the derivation of the refraction formulae of Cassini, Simpson, and Bradley, there is no suggestion of the incomparably more important modern work of Gyldén and Radau. Bessel's work finds recognition in one line of a footnote and tables of the refraction are wholly ignored save for brief reference to two minor adaptations, of British origin.

Per contra, from the standpoint of the student of mathematics, there is much to be commended and the experienced astronomer will find novelty and interest in the methods of approach to familiar problems. Probably the most conspicuous illustration of these is to be found in the chapter devoted to the "Generalized Instrument," in which the author constructs

a mathematical theory of a hypothetical instrument, of which the transit, the equatorial, altazimuth, almucantar, etc., are special cases whose respective theories result from the general theory by the introduction of suitable limitations. As the *Oxford Note-Book* puts it:

> The time is come, Sir Robert said,
> To make a great combine
> Of all the various instruments
> Down which a star may shine.
> The following simple formula
> Will bring them into line.

Admirable as the chapter is from the standpoint of analysis and valuable for its breadth of view, it presents points of analogy to a generalized confession of faith of which all creeds should be special cases, its theoretical comprehensiveness and practical limitations making it objectionable to the partisans of each. Thus most observers with a transit instrument would consider inadequate for practical uses a theory which ignores the spirit level as an auxiliary apparatus and suggests only nadir observations as a means of determining the inclination of the axis.

The book will be seen at its best if considered as a textbook of a special kind of applied mathematics in which the student who seeks concrete applications of pure theory will find material excellently suited to his purpose, in which the student of education may obtain interesting glimpses of English university practice, and in which the future expositor of spherical astronomy will find much that is worthy of his consideration.

G. C. COMSTOCK

The Story of the Comets. By GEORGE F. CHAMBERS. Oxford: The Clarendon Press, 1909. 8vo., pp. 256; Figs. 106. 6*s*. net.

Chambers' *Handbook of Astronomy* is a considerable work, treating of the sun, moon, planets, and comets. The present book comprises the portion of the *Handbook* which was devoted to comets, which is now enlarged and brought up to date under the above title, with the added phrase, "simply told for general readers."

Chambers' books on astronomy are always interesting. They have been, for a great many years, a storehouse to which the public, and also the astronomers, could apply for general information on the subject. Today there are many other sources of general information of this kind, but Chambers' books are still of much value for reference, especially where

the information sought belongs to the older astronomy. It is therefore a pleasure to see the present book under its new form, and modernized. There is much improvement in this volume over the previous work. We still find in it, however, many of our old friends, the wood engravings of former days. These pictures will always have a special charm about them, notwithstanding that they seldom look very much like the objects they represent. Some of these woodcuts are classical and have been borrowed freely for use in many other works.

Some photographs of recent comets have been introduced, but there is not so varied and complete a selection as should be in a work of this kind. Some of these photographs have been unintentionally falsified in the reproduction; especially unfortunate in this respect is Fig. 22, Plate VII, where the entire comet seems to be enveloped in an outer casing, or sheath, of nebulosity, which is fairly definite, and which no one could possibly distinguish from a real cometary phenomenon. Fig. 23 on the same plate suffers somewhat from a similar defect, which, however, is not so misleading. Fig. 99 of Plate XXVI is falsified outright by an attempt of the engraver to get a black sky by cutting away the sky about the image. This gives a very incorrect impression of the comet, which is bizarre enough without the ill-treatment it has received. Fig. 19 of Plate IV is defective in the same manner—the engraver having removed all the sky and stars, leaving what he thought might be the comet. The result gives the comet a rather gay appearance, which, however, is not nearly so startling as the original. The two photographs of Plate VIII are good reproductions. All these photographs, though they are not so credited, were made by the present reviewer, which will explain the disappointment in the unsatisfactory reproduction of all but the last two. By some mistake, the exposure time of one of the photographs is wrongly given. Fig. 22, Plate VII, should read September 30^{d} 20^{h} 22^{m} G. M. T. instead of 17^{h} 16^{m}.

There are two good reproductions, Plates V and VI, which are from excellent photographs by Mr. P. Morris. A serious omission in these two plates, however, is the exact time of exposure. The dates alone are given. Especially is this omission unfortunate in the photograph of October 15, 1908, where the exact time is of the utmost importance. In the days of hand drawings of comets, this omission would not have been serious, but today, when such illustrations are the actual photographs themselves, it is very important that the exact time of exposure be given, whether the picture appears in a popular work or not.

The histories, with fairly good descriptions, of all the great comets are gone into quite thoroughly. In this respect there is an extensive account

of Halley's comet which is important at this time when this celebrated object is once more visible in our skies.

A new chapter has been introduced which is of great interest from a literary standpoint. It is devoted to "Comets in History and Poetry." The chapter on "Comets in the Spectroscope" is important also, for it gives somewhat of a historical account of the various efforts (successful and otherwise) to investigate the nature of these bodies from a spectroscopic standpoint. In this chapter Mr. Chambers justly emphasizes the importance of the objective prism for cometary work where motion in the line of sight is not considered.

The title of Plate XIX^a, "The Comet of 1862 (iii)," is certainly misleading to the lay reader, who will see in the drawings, which represent a telescopic view of a small portion only of the phenomena connected with the nucleus, a representation of the comet as a whole. A less misleading title would be "Phenomena of the Nucleus and Jets in the Head of the Comet of 1862 (iii)." The use of the small Roman numeral, instead of the larger one, designating a comet by the order of its perihelion passage, as "the Comet of 1861 (i)" instead of "Comet I 1861," is to be regretted.

In speaking of the improvements in this book, one of the best of the changes that have been made, and one that all fair-minded persons will heartily applaud, is in the statement concerning the observations of a double comet which appeared in 1860, and was observed only by Liais in Brazil. In the edition of 1889, p. 409, the statement is made that—

> It is to be regretted that this object remained visible for so short a time . . . . and that our knowledge of it depends on the authority of but one observer, and he a Frenchman.

In the present volume, p. 16, the obnoxious phrase, "and he a Frenchman," is omitted.

The book is to be commended to those, whether astronomers or general readers, who take any interest in these wonderful bodies, the comets.

E. E. B.

An Atlas of Absorption Spectra. By C. E. KENNETH MEES. New York: Longmans, Green & Co., 1909. Pp. 74.

The absorption of the various dyes used in the manufacture of light-filters for photographic purposes has been investigated in the research laboratory of Wratten and Wainwright under the direction of Mees, and the results published in a very useful little atlas of octavo size. The twelve

pages of text describe the material and apparatus used, and give an index of the dyes and filters. Then follow 43 pages containing 170 halftone cuts showing spectral intensity-curves of the dyes. Each cut carries an approximate scale of wave-lengths. There are also given the curves for 70 stock filters, including 7 so-called "Monochromat" filters which transmit 300 to 600 Ångströms.

This atlas supplements that of Uhler and Wood, since it gives absorption spectra as far into the red as λ 7800, but nothing in what is usually considered the "infra-red," though such an extension is mentioned in the text. By the aid of this atlas one may select a commercial filter suitable for almost any photographic purpose.

J. A. P.

Cours d'Astronomie. Seconde Partie: Astronomie Pratique. Par H. Andoyer. Paris: A. Hermann et fils, 1909. Pp. 304, with 60 diagrams. Fr. 10.

Following as it does the author's previous work on theoretical astronomy, the present volume completes a textbook for the technical student of astronomy which is quite usable. The author does not attempt to write a complete treatise on the subject but, in common with most writers of textbooks, confines himself to introducing the reader to general methods, leaving him prepared to follow whatever special studies he may desire.

The work is divided into three books of seven chapters, with a short supplementary chapter treating briefly of the determination of an elliptic or parabolic orbit. The first book deals with principles of computing and the method of least squares. This book contains 63 pages. Book II has 109 pages, and treats of instruments, classified as accessory, principal, and miscellaneous. The last book contains 90 pages and deals with observations: first those made for deriving the fundamental constants of astronomy, such as precession and nutation, then those made for determining the observer's position on land and sea. In each case the necessary formulae are derived and the final equations are given in convenient form.

The practical astronomer in looking through this recent work notices with regret the absence of a chapter on the determination of the place of a celestial body from photographic plates, half a page alone being accorded to this subject. The photographic method is now coming into such widespread use in precise astrometry that the value of the volume would have been enhanced appreciably had a score or two of pages been devoted to

deriving the formulae necessary to both rigorous and approximate reductions of stellar photographs.

The book is well printed, and the diagrams are good. It is to be hoped that there will be a call for a second edition of the first part, so that it may have the same typographical appearance: it may be recalled that it was reproduced by the zinc process from a manuscript copy.

O. J. L.